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Entered at the Post Office at Lancaster, Pa., March 14, 1928, as second-class matter under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on July 3, 1919.

Published by

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

Prince and Lemon Streets, Lancaster, Penna., and

15 South Seventh Street, Philadelphia, Penna.

SIX DOLLARS PER YEAR (Foreign Postage Additional) **SINGLE NUMBERS, SIXTY CENTS**

Indexes to the semi-annual volumes of the JOURNAL are published with the June and December numbers. The contents are also indexed in *The Industrial Arts Index.*

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Established 1877 **LANCASTER, PA.**

[*Printers of Journal of The Franklin Institute*]

JOHN HAGAN CO., INC.

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COMLY STREET AND ALGON AVENUE
PHILADELPHIA, PA.

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 216 DECEMBER, 1933 No. 6

CLOUD PHOTOGRAPHS OF COSMIC-RAY STÖSSE.*

BY

GORDON L. LOCHER, Ph.D.,

National Research Fellow.

BARTOL RESEARCH FOUNDATION

Communication No. 80.

INTRODUCTION.

Large instantaneous increments in the ionization by cosmic rays are found in ionization chambers that are surrounded by, or in the vicinity of, massive material. These large fluctuations are generally called "Stösse," "bursts." or "spurts of ionization"; their magnitudes sometimes correspond to the passage of several thousands of electron tracks throught the measuring apparatus. The Stösse have mostly been studied by ionization methods;[1, 2, 3, 4, 5, 6, 7, 8] Swann and Montgomery [9] combined an ionization chamber with a coincidence set of Geiger-Müller counters, finding that large increments in the ionization were frequently accompanied by the simultaneous discharge of

* Part of this paper has been printed in the *Physical Review*.

[1] Hoffmann and Pforte, *Phys. Zeits.*, **31**, 347 (1930).

[2] Steinke, *Phys. Zeits.*, **31**, 1019 (1930).

[3] Schindler, *Zeits. für Phys.*, **72**, 625 (1931).

[4] Steinke and Schindler, *Zeits. für Phys.*, **75**, 115 (1932).

[5] Messerschmidt, *Zeits. für Phys.*, **78**, 668 (1932).

[6] Swann and Street, *Phys. Rev.*, **40**, 1049A (1932).

[7] Messerschmidt, *Naturwiss.*, **21**, 285 (1933).

[8] Steinke, Gastell and Nie, *Naturwiss.*, **21**, 560 (1933).

[9] Swann and Montgomery, *Phys. Rev.*, **43**, 782A (1933); *Phys. Rev.*, **44**, 52 (1933).

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

the counters, which were about a meter apart, outside the chamber.

The infrequency with which Stösse occur makes the accumulation of data on them slow. (Relatively large bursts are produced, roughly, at 3 per hr. per 100,000 cc. of absorber.) At the present time it can be said that the rate of their production is nearly proportional to the *number* of atoms in the absorbing material, for dense matter; that many of the particles have ranges of more than 10 cm. in lead (some 20 cm.), and that the ionization per Stoss depends on the atomic number of the absorber in which it is generated. From a maximum ionization jump corresponding to about 4000 electron tracks or 260 proton tracks, observed in one instance,[8] the bursts appear to taper off to sizes that are too small to be recognized, with no sharply defined classes of size.

From the information now available, it seems impossible to tell whether the ejected particles derive their energy wholly from the primary cosmic ray, or draw part of it from the nuclei of disrupted atoms, nor can we say, in view of the discovery of the apparent synthesis of particles from photons, whether the particles ejected from Stösse all previously *existed* in the disrupted atoms; and, finally, we cannot be certain that a Stoss is always produced by a *single* primary cosmic ray, rather than by a *shower* of primary disrupting agents from outside the earth's atmosphere.

The method of photographing cloud tracks of the disintegration products of Stösse promises to be a fruitful means of attack on the problem. But for a Stoss rate of 1 per hr., the chance of getting a significant photograph is about 1/36,000, if the chamber is operated in the customary manner. Anderson [10] did accidentally get one burst, but the solution lay in a simple modification of the method of Blackett and Occhialini,[11] who automatically set off the expansion of a cloud machine immediately *after* the ionizing particle discharged a coincidence pair of cosmic-ray counters in line with the cloud chamber. In the course of their experiments, they not only verified the observation that the particles discharging the

[10] Anderson, *Phys. Rev.*, **43**, 368 (1933).
[11] Blackett and Occhialini, *Proc. Roy. Soc.* A, **139**, 699 (1933).

counters produce tracks,[12] but obtained photographs of several interesting bursts, as well.

EXPERIMENTAL ARRANGEMENTS.

A cloud chamber 15 cm. in diameter has been arranged to be set off immediately after the simultaneous discharge of three Geiger-Müller counting tubes, each 100 cm.^{2} in cross-sectional area, placed two above and one below the chamber, but as far *out of line* as possible; no single particle, nor downward-directed branched pair originating near the chamber can set off the counters. The smallest sphere containing the counters, which have a maximum separation of 80 cm., has a volume about 500 times that of the cloud chamber, so that the fraction of the tracks from the Stösse which pass through the cloud chamber may be small, if the point of origin is remote.

Of the triple-coincidence counting rate, 1.26 per hr., it is estimated from the photographs taken that about one-third of the discharges are from Stösse, and two-thirds from branched tracks and small groups of tracks. Surrounding the chamber are about 1350 lbs. of massive material, consisting of 750 lbs. of lead, 400 lbs. of copper and brass, and 200 lbs. of iron. A cloud atmosphere of argon at 64.5 cm. pressure is used. The specific ionization of tracks in argon is high; the relatively high viscosity makes the tracks persist better than in air; the expansion ratio is small (1.18, as compared with 1.3 for air), and the probability of obtaining elastic-collision recoil atoms from any neutrons present is relatively high. Since the ionizing particles traverse the chamber about 0.01 sec. before the expansion, the tracks are somewhat diffused by thermal agitation and by the expansion; equality of diffuseness of tracks of like densities serves to establish approximate simultaneity of their formation, and makes it easy to distinguish between pre- and post-expansion tracks. Stereophotographs are taken with two cameras whose optic axes intersect in the chamber at an angle of 22°.

The connecting link between the counter set and the cloud machine is a thyratron (G.E. Co. Type FG 67), which acts through a quick-acting electromagnetic trigger to release a

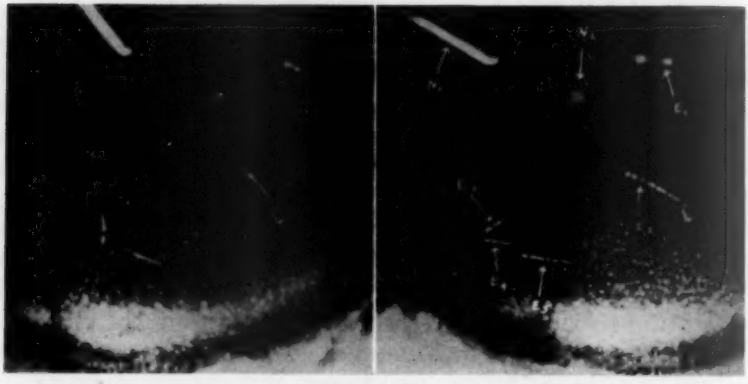
[12] Mott-Smith and Locher, *Phys. Rev.*, **38**, 1399 (1931).

mechanical drive mechanism that is normally held in readiness by vacuum force and spring tension.

RESULTS AND DISCUSSION.

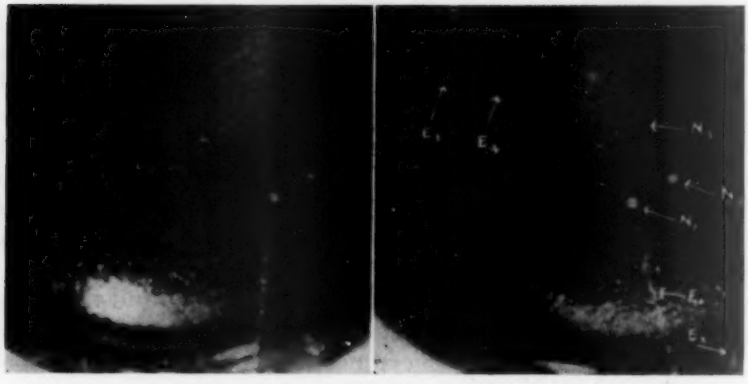
Figures 1, 2, and 3 are stereophotographs of interesting Stösse; Figs. 4, 5, and 6 are single photographs of three

FIG. 1.



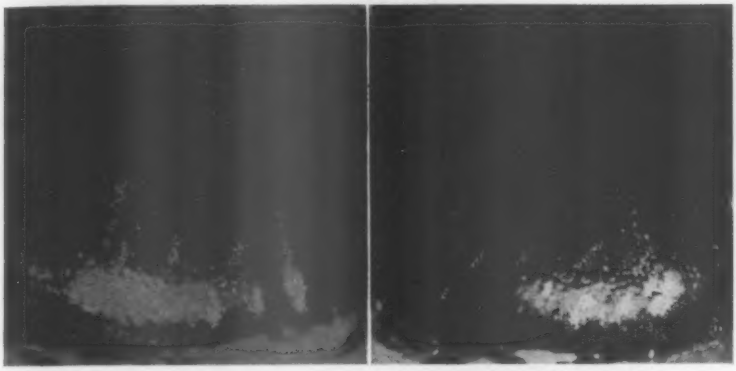
Stoss with two nucleus tracks (N), and 5 electron tracks (E). E_1, E_2, and N_1 converge to a point in the lead, above and behind the chamber. E_3, E_4, and E_5 converge to another point. N_2 is believed to be the track of an argon atom recoiling after elastic collision with a neutron. The heavy nucleus track, N_1, emerges from one of the centers of disintegration and ends in the chamber, with a sharp bend. The range of this particle must have been > 5 mm. in lead (Mag. 0.54).

FIG. 2.



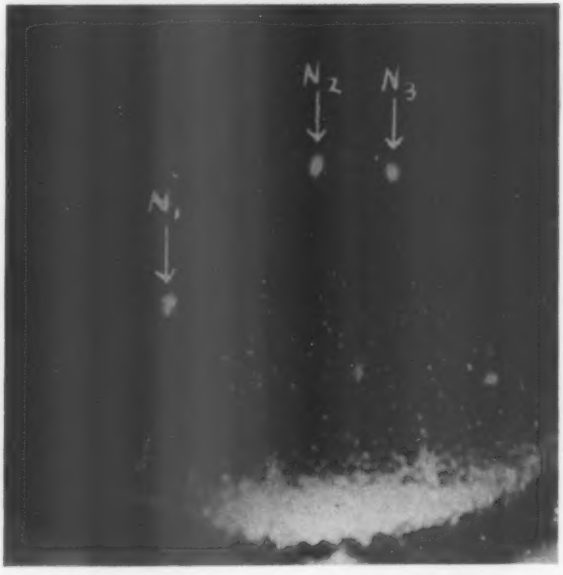
Stoss with 4 electron tracks, 2 neutron-recoil tracks, N_1 and N_2, and a long, diffuse nucleus track, N_3, near the bottom of the chamber (Mag. 0.54).

FIG. 3.



Stoss with 13 tracks of the same "age." Eleven of these converge in a lead block 40 cm. above and in front of the cloud chamber; the other two appear to be secondary branches originating in the glass lid of the cloud chamber (Mag. 0.57).

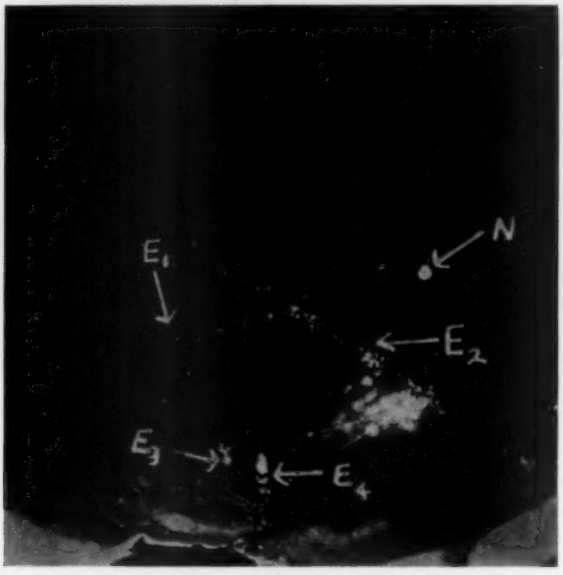
FIG. 4.



Stoss with 15 tracks: 11 simultaneous pre-expansion electron tracks, 3 neutron-recoil argon-tracks, N_1, N_2, and N_3, and a post-expansion electron track. Most of the electron tracks traverse the chamber in nearly vertical directions, but could not have come from less than 4 points of convergence (Mag. 0.83).

others.[13] Conspicuous features found in nearly every burst photographed are the non-convergence to a single point of the (simultaneous) tracks of each burst, and the presence of very short nucleus-tracks, originating and ending in the gas, which closely resemble the recoil-atom tracks formed by beryllium neutrons in the same atmosphere. Blackett and Occhialini [11]

FIG. 5.



Four electron tracks of the same age, and a neutron-recoil argon atom, *N*. E_1 and E_2 do not intersect; E_3 and E_4 seem to intersect in the iron of the arc used for illumination (Mag. 0.83).

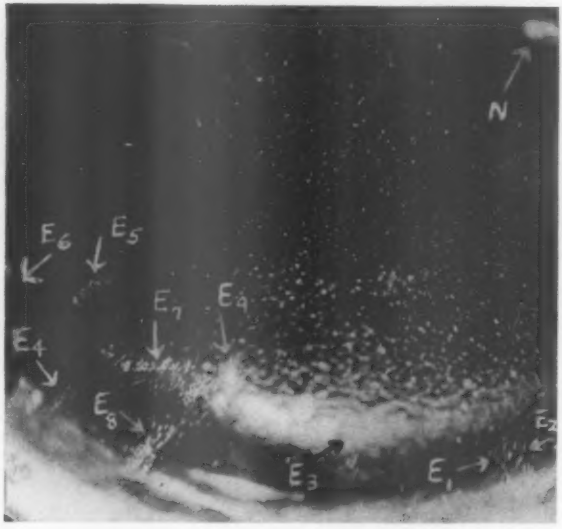
mention cases of showers emanating from more than one point, and the burst found by Anderson showed the same characteristic.

If we postulate that each burst derives its energy from a *single* primary entity, *we must suppose that the primary entity generates secondary ones, which, in turn, are very efficacious in*

[13] In preparing these photographs for reproduction, some faint tracks and other detail have become lost; the density relations between the tracks are less faithful than on the original negatives, from which the numbers, kinds, and points of convergence were, of course, taken.

setting up tertiary centers of disruption, since the (tertiary) track-foci are relatively close together. It seems very unlikely to the writer that a single *primary* cosmic ray establishes the observed points of disintegration directly, without the aid of a secondary agent (that is presumedly non-ionizing), since in one case, at least, the several track-foci are not collinear. On the basis of the evidence so far available, it seems improbable to the writer that the secondary entities are photons. The

FIG. 6.



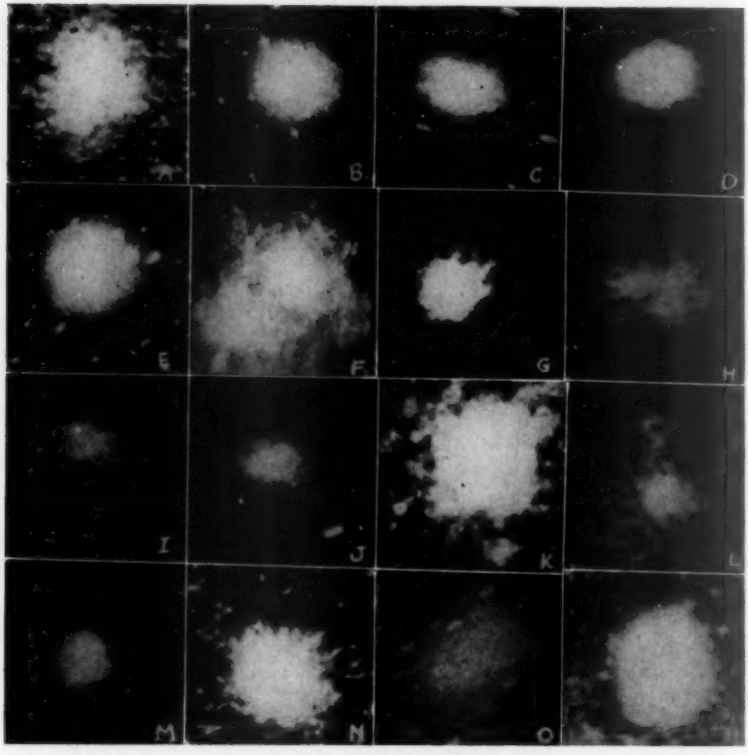
Stoss with at least 9 electron tracks and one nucleus track in the cloud chamber. E_1 and E_2 are nearly horizontal and in line with the arc; E_3, E_4, and E_5 are nearly parallel and vertical; E_7, E_8 and E_9 diverge upward from a point near the bottom of the chamber. N is believed to be a neutron-recoil nucleus; it is somewhat out of focus, and appears larger than it really is (Mag. 0.8).

necessarily high energies of such photons would be incompatible with the observed facility of their absorption by matter near the cloud chamber, unless their numbers were so very great as to impose excessive requirements on the energy drawn from the primary entity. (On the other hand, it seems reasonable to expect that some low-energy quanta, at least, are set free from Stösse.) Against the possibility that the secondary agents are *ionizing particles*, is only the fact that on no picture was there a track *observed* which linked two track

foci together. Further cloud pictures of bursts should decide this question.

Figure 7 shows photomicrographs of some of the short "recoil-atom" tracks from Stösse, also some recoil-atom tracks from Be neutrons, in the same cloud atmosphere, for com-

FIG. 7.



A through *J*, short nucleus tracks from cosmic-ray Stösse photographs, attributed to argon atoms recoiling from elastic collisions with neutrons emitted from the Stösse. *K* through *P*, recoil-atom tracks formed in the same atmosphere, but with beryllium neutrons from a Po-Be source. The energies of the atoms of the two groups are of the same order of magnitude (Mag. 3.9).

parison of the ionization density and energy. The similarity of the two groups is very evident. The writer believes, accordingly, that neutrons are generated, or liberated, in cosmic-ray Stösse. Tracks of this kind are recongizable with considerable certainty because of the enormous density of

their ionization. The use of argon probably facilitates the detection of the neutrons considerably; Bonner [14] found from ionization measurements that the target area of the argon atom for Be neutrons is about 17 times that of hydrogen, or 4.85 times that of nitrogen. Since the tracks of the Stösse do not converge to single points, it is impossible to tell from what material the neutrons arise; but the infrequency of appearance of recoil-atom tracks on pictures other than those of Stösse, indicates that they somehow arise from disintegration processes, so that their presence here need not be interpreted as contradictory to the results of Curie and Joliot,[15] who failed to detect neutrons in primary cosmic rays.

The numbers of short recoil-atom tracks from Stösse is about the same as the number of Be neutron recoil-atom tracks from a Po-Be source of about 0.05 millicurie radium equivalent, placed on top of the cloud chamber, or 1 to 10 millicuries at the Stoss track-foci. But the energy and ionization characteristics of the Stoss neutrons are unknown, hence a comparison of their number with those of Be neutrons, from the relative numbers of recoil atoms, is a dubious extrapolation of ideas.

The (secondary) agents responsible for ejecting the convergent groups of tracks found in Stösse are still unidentified. If the low-energy recoil tracks observed are produced by high-energy neutrons, the latter *might* satisfy the difficult requirements of an agent that has extremely high energy, but produces numerous subsidiary points of disintegration within a small region. But this hypothesis is based rather on our lack of knowledge of the processes by which such neutrons lose their energy, than on our knowledge of them.

These experiments are being continued with masses of aluminum about the cloud chamber, in place of lead, in order to determine whether the more intense ionization produced by Al Stösse [8] results from the generation of many nucleus tracks, or from more abundant electron tracks.

Meanwhile, an apparatus now under construction for another experiment will be used for examining the remote possibility that the Stösse are manifestations of the arrival of

[14] Bonner, *Phys. Rev.*, **43**, 871 (1933).

[15] Curie and Joliot, *Jour. Phys. et Rad.*, **4**, 492 (1933).

infrequent, instantaneous, very intense showers of primary cosmic-ray photons or particles from interstellar space, perhaps covering large areas, and possessing the power to disintegrate heavy nuclei. However enormously improbable such an occurrence may seem, because of the energy involved in such a shower, it would explain the closeness of the centers of disintegration indicated by Stoss photographs, and seems not incompatible with any other cosmic-ray experiment so far performed. The apparatus consists of eight triple-coincidence counter sets, operating independently, but recording the discharges on the same moving film. The sets, mounted vertically, and capped with blocks of massive material will be operated several meters apart. Their coincidence records will be examined for simultaneous discharges of two or more sets, with especial regard to the geographical positions of the sets concerned. Information should also be forthcoming from this experiment in regard to the branching of high-energy corpuscular tracks at high altitudes. The geometry of the sets and the distances between them will determine the lowest point from which such branched tracks could produce simultaneous discharges.

The writer is indebted to Dr. W. F. G. Swann for suggesting the cloud-photography of Stösse, for discussion of the subject, and for criticisms of this paper.

THE PHOTOGRAPHIC PROPERTIES OF SILVER SULFIDE.*

PART 2. THE PRINT-OUT EFFECT—CHEMICAL ASPECT.

BY

K. HICKMAN AND W. WEYERTS.

Silver sulfide, long respected as one of the most stable of photographic pigments, is sensitive to light and can form the active part of a print-out material—it exhibits a *photographic effect.* The photo-voltaic,[1] the photo-conductive,[2] and the photo-emissive[3] properties of silver sulfide have long been known, but no reference in the literature of the last 40 years has been found describing a photographic effect. The effect came to our attention accidentally while collecting data on the nucleating power of Ag_2S suspensions.[4] It was noticed by one of us† that suspensions in certain solutions darkened perceptibly during measurement in the photometer, and it was soon determined that the lamp—and the light of the lamp rather than its heat—was responsible, though the "heat rays" to our surprise were evidently assisting. Only a particular kind of silver solution conferred the darkening property, and the excellent stability towards light of silver sulfide under more ordinary conditions was not brought into question. Indeed there is little doubt that the sulfided image of a bromide print is at least as stable as the untoned silver image. Silver sulfide, in the dry powdered state, or wetted with pure water or with dilute acid or alkali, and colloidal silver sulfide in neutral, acid, or alkaline solution, shows no noticeable alteration in sunlight. Silver sulfide in contact with the special solutions shows immediate and powerful darkening under similar conditions of exposure.

The darkening effect can be turned to useful account in various ways, one of which is for intensifying and toning weak sulfided silver images on films or paper. It has been

* Communication No. 522 from the Kodak Research Laboratories.

† W. Weyerts.

found that all silver sulfide images are amenable to treatment but the effect is most marked with images of a weak yellow color, or images produced in specially modified bleaching and sulfiding solutions. This aspect will be dealt with in Part 3 of these papers.[5]

The solutions which show the effect with silver sulfide are, in general, reducing solutions containing free silver ion and, in particular, solutions of silver sulfite in an excess of sodium sulfite, and solutions of silver nitrite in an excess of sodium nitrite. Solutions of silver sodium formate or tartrate confer a just perceptible sensitivity. Solutions containing silver and hydrazoic acid are slightly sensitive, but mixtures of silver salts and the more obvious reducing agents, such as hydroquinone, hydrazine, phenyl hydrazine, are inactive. When acid, they show no sensitivity, and when alkaline, they darken spontaneously.

Preliminary work with silver sulfide images in photographic film or paper showed that the darkening is caused by the deposition of metallic silver on the silver sulfide, often in quantities many times the mass of the sulfide—the limiting factor seeming to be the optical obscuration of the active surface. The silver can be dissolved by ferricyanide and hypo, revealing the original sulfide image substantially unchanged and in a condition for further darkening in silver sulfite solution by light. Prolonged insolation, or repeated short exposures with alternate removals of the photo silver, reveals some attack of the silver sulfide. It is thought, however, that this wastage is of a secondary nature.

It was soon suspected that the spectral sensitivity extended into the infra-red and this was confirmed by our being able to intensify a sulfided bromide print by exposure to a lump of red hot iron while the print itself was immersed in sodium silver nitrite solution cooled by ice. The spectral sensitivity is important because of its theoretical implications, not only in connection with the immediate problem, but in its relation to high speed emulsion sensitivity. A separate paper, numbered Part 4 in this series, will be devoted to this aspect of the problem. It is sufficient here to state that the sensitiveness extends from the violet to an apparent maximum (using a prism spectrograph and tungsten filament) at 1.1 μ in

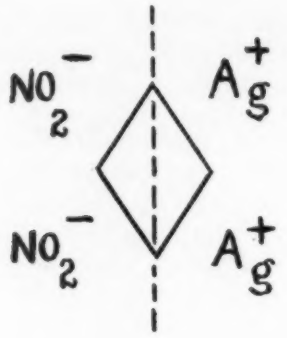
the infra-red, and then diminishes rapidly to complete insensitivity at 1.4 μ, the total range corresponding well with that of the photoconductance of Acanthite,* as measured by Coblentz.[6]

The reaction, to wit, the deposition of silver on silver sulfide, is one of catalysis. Both silver sodium nitrite and silver sodium sulfite deposit silver spontaneously on long standing, and the double silver sulfite can be made to give up its silver in a few hours if subjected to vigorous aeration. The spontaneous deposition is slightly quicker in the presence of colloidal silver sulfide and increases rapidly with rising temperature;—in light, the reduction begins at once and is enormously more rapid. There are thus two reactions: a slow dark reaction increasing with temperature, and a light reaction independent of the dark reaction which it nevertheless stimulates to a certain small extent without itself being influenced by the magnitude of the dark reaction. The stimulation of the dark reaction by the photo silver may be demonstrated by dividing into two portions a silver sulfite solution containing silver sulfide sol and illuminating one portion for a short time. After storage in the dark for a few days it is found that the illuminated sample has accumulated slightly more reduced silver than the unilluminated.

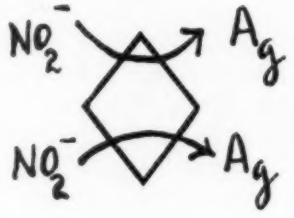
The light reaction is interesting in that it shows sometimes a negative temperature effect. Working in nitrite solutions loaded with glycerin in which, at ordinary temperatures, the darkening speed is the same as in plain water solution, the speed is about twice as great at $-16°$ C. as at 26° C.

The theoretical argument, seeking to correlate the various phenomena, must perforce be reserved until after a discussion of the spectral sensitivity and hence, until a future paper. It may be anticipated, however, by stating that the silver sulfide suspensions and sulfided photographic images behave as though they were aggregates of Ag_2S crystals which present two kinds of faces, those able to adsorb silver cations and those adsorbing the companion reducing anion. The sulfite reduction process evidently involves many intermediates but with nitrite the simple picture may be drawn,

* A crystalline mineral form of silver sulfide.



which involves in light, the equally simple electron interchange:



represented by the *chemical* equation:

$$2\ AgNO_2 + H_2O \xrightarrow{\text{light}} 2\ Ag + HNO_3 + HNO_2.$$

The introduction of water into the equation is justified by the fact that the darkening in wet layers of nitrite and sulfide is so much more rapid than in dry. It must be emphasized that the light-sensitive unit is not merely the silver sulfide, but the complete system of sulfide, electrolyte and appropriate ions.

Accepting, for a moment, the elementary picture just presented, it is evident that the sensitivity is likely to be modified by additional reagents chiefly as they modify the reacting ionic layers. Thus, the "fastest" silver sulfide is the purest. A suspension made from dilute silver nitrate, with a slight excess of H_2S water, the residual sulfide being removed by nitrogen, provides at once the most sensitive material, and a material of reproducible standard speed. Precipitates and

sulfide images of inferior speed may be improved by addition of zinc and manganese salts, etc., but these slightly depress the sensitivity of the best material. Iron salts, notably as the ferro- and ferricyanides, depress the sensitivity and *any* reagents having an affinity for silver ions, and we name, specifically, ammonia, thiosulfate, cyanide, or excess of sulfite, practically banish sensitiveness.

Gelatin is a powerful depressant. The addition of three parts in a million of water to the Ag_2S suspension (100 parts per million) reduced the sensitivity 20 per cent. and large quantities reduced the speed to a tenth the initial value. Some sulfide images in the photographic jelly layer were relatively insensitive—perhaps 100 times less than the colloidal suspension.

Alterations in acidity within the limits pH 5–pH 10, which were all that were practicable, scarcely affected the pure suspension but modified the restraining effect of gelatin profoundly. A restraint of ten times at pH 10 vanished almost completely at pH 4.8, the isoelectric point of gelatin. The addition of large quantities of sodium sulfate at pH 8.4 also restored the sensitivity. The pH series could not be taken to the acid side of the isoelectric point because all the sodium sulfite became decomposed and the silver sulfite thrown out of solution. It is hoped that other means may be devised for testing the action in more acid media.

The sulfite and nitrite effects, so similar in the main, differ in detail. At high concentrations of the double silver salts, the sensitivity of the silver sulfide is similar in the two cases, and is relatively unaffected by change of concentration. At low concentration, the nitrite sensitivity persists unimpaired as far as it could be followed (to a few parts Ag^+ per million), the falling off in yield of silver being readily accounted for by shortage of material to replace that changed by light at the sensitive surface. The sulfite sensitivity, on the other hand, disappears abruptly at a definite small concentration of silver ion which is still twenty times that of the least convenient nitrite measurement. A parallel case exists with sulfided photographic step wedges. In the nitrite solution all the steps intensify, but in the sulfite there is a small threshold density of deposit below which no darkening takes place. The provi-

sional inference may be drawn that the nitrite darkening involves a direct ionic interchange, while the sulfite darkening occurs through the formation of an intermediate compound which must reach a critical concentration before silver is deposited.

EXPERIMENTAL—THE CHEMICAL MATERIALS.

The factors governing the preparation of silver sulfide suspensions of reasonable purity have been detailed elsewhere.[7] It would be desirable in the present work to have colloidal sols of great stability, possibly prepared with gelatin, if it were not for the depressing effect of the latter on the sensitivity. The suspensions were therefore made more simply by adding 10 cc. of water saturated with hydrogen sulfide at room temperature, to one liter of water containing 0.1 gram $AgNO_3$, and bubbling nitrogen from a cylinder through the covered liquid for 1 hour. The resulting clear brown suspension remained in good condition for one day and would endure without settling in the silver depositing solution providing that it was not stirred and the exposure ($I \times t$) was not excessive. Heavy exposure would cause the particles to grow to such a size that settling would occur in a few minutes. It is interesting to note that Ag_2S suspensions which passed unhindered through fine filter paper, even after addition of silver nitrite, became completely filterable after small light exposure in the intensifying solution.

The sodium nitrite used was Baker's Pure "Analyzed" containing 3 per cent. $NaNO_3$, no iron and traces (less than 0.1 per cent.) of halogen.

The sodium sulfite in the majority of the experiments was Eastman Kodak anhydrous powdered photographic material. This contained traces of iron and halogens, some sulfate, and a number of equilibrium products such as thiosulfate and thionates. The "pure" grade analytical sulfites were free from non-sulfurous impurities but proved to contain mixtures of the sulfur acids. Check experiments against the E. K. sulfite were constantly made, therefore, with sulfite freshly prepared from strontium sulfite. The strontium sulfite was precipitated from hot strontium chloride and "pure" sodium sulfite solutions acidified with HCl—washed by decantation,

dried rapidly, and weighed. The weighed samples were decomposed with equivalent quantities of sodium carbonate, filtered and the solution made up to standard volume and checked by iodine titration. Such solutions behaved differently from the commercial sulfite solutions, conferring less sensitivity on the silver sulfide. They could be brought to normal sensitivity by:

making acid,

" " and again neutralizing,

adding SO_2 gas,

" small quantities of sodium tetrathionate.

THE EXPERIMENTAL METHOD.

The light-sensitive mixtures were compounded by mixing the appropriate volume of the sulfide suspension with a volume of liquid containing the other constituents, and exposing the mixture in a flat glass cell 11 cm. high, 8.2 cm. wide, and .75 cm. thick. The cell was held in a large air thermostat maintained at the desired temperature to within 0.25° C., and was illuminated by a 100-watt tungsten coil-coil projection lamp, rated 115 V. and run at 110 V. ± 1 V.

The measurement of growth of silver deposit was made as follows:

The original silver sulfide suspension was matched colorimetrically with a sol made from silver nitrate, sodium chloride, gelatin and thiosulfate and darkened with H_2S water. The ratio of the quantity of silver required to yield the same obscuring power under the two conditions was sufficiently near unity to be considered unity for this work. The correlation between density and mass Ag_2S was thus established under working conditions.

The exposed solutions were filtered and the filtrate rejected. The precipitates were washed well with hot water, and then treated with a little bromine water till completely bleached. They were washed and dissolved in hypo (5 cc. of 10 per cent. solution) containing some sodium sulfite (1 cc. of 10 per cent.) to neutralize any free .Br remaining; gelatin was added; the mixture was darkened with H_2S water and then made up to constant volume and measured in the photom-

eter.[8] The density ratio between the original sulfide suspension and the final regenerated suspension afforded the degree of growth during the experiment. When a second experiment was made to check any figure, the dissolved bromided precipitate was diluted to give, after darkening, approximately the same density as the original sulfide sol. The dilution was then allowed for in the calculation.

THE EFFECT OF CONCENTRATION.

The simplest intensifying solution consisted of silver nitrite dissolved in a little more than a sufficient excess of sodium nitrite. The excess required differed with the total concentration, but a solution containing

Sodium nitrite	20 grams
Silver nitrate *	2 "
(Water to 100 cc.)	

could be diluted indefinitely without precipitation.

The equivalent sulfite intensifier was made with a neutral sulfite mixture composed of one part by weight of sodium bisulfite and four parts of anhydrous sodium sulfite. This mixture gave a solution neutral to litmus over a sufficient range of dilution. The intensifier stock solution contained:

Sulfite mixture	10 grams
Silver nitrate	2 grams
Water, to	100 cc.

The solutions were then diluted in stages to form, with a standard volume of sulfide suspension, two exponential dilution series. Each member of the series was exposed for two minutes at 10 inches from the lamp at 26° C. in the thermostat and the resultant silver estimated. The analytical figures for the nitrite series are reproduced below (Table I).

The sulfite series did not yield as concordant results owing to the difficulty of controlling the composition of the solutions. However, the figures are trustworthy within useful limits. The yield of silver for the two series is shown in the graphs of

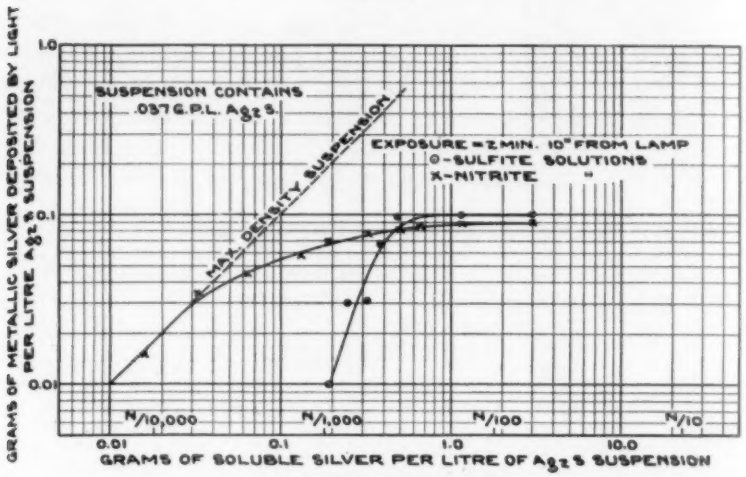
* No difference in action could be observed between solutions made with silver nitrate and those in which the silver nitrite was filtered off and redissolved in pure sodium nitrite. The same remark applies to the silver sulfite of the sulfite intensifier.

TABLE I.

Concn. of $AgNO_3$.	Vol. of Stock Soln. Taken.	Vol. of Silver Sulfide Suspension.	Total Volume of Soln.	Dilution of Photometered Solution.	Photometer Reading.	Density, Dilution Allowed for.	Density Gain.	Maximum Density Increase Obtainable from Solns. if all Soluble Silver Reduced
None	None	25 cc.	50 cc.	50 cc.	54.3	.15	—	—
5 gms. per liter	12.5 cc.	" "	" "	100 "	58.2	.57	.42	15.0
	12.5 "	" "	" "	" "	58.0	.56	.41	15.0
2 gms. per liter	5 "	" "	" "	" "	57.8	.55	.40	6.0
	5 "	" "	" "	150 "	55.2	.55	.40	6.0
1 gm. per liter	2.5 "	" "	" "	" "	55.3	.55	.40	3.0
.7 gm. per liter	1.75 "	" "	" "	100 "	57.7	.54	.39	2.10
.5	1.25 "	" "	" "	" "	57.3	.51	.36	1.50
.3	0.75 "	" "	" "	" "	56.9	.48	.33	.90
.2	0.5 "	" "	" "	" "	56.1	.42	.27	.60
.1	.25 "	" "	" "	" "	55.2	.36	.21	.30
.05	.5 "	" "	" "	" "	54.5	.31	.16	.15
.025	*stock 4* .25 "	" "	" "	75 "	54.2	.22	.07	.075
.001	*stock 4* .1 "	" "	" "	50 "	51.4	.05*	—	.038

* Ag_2S insufficiently intensified to filter completely.

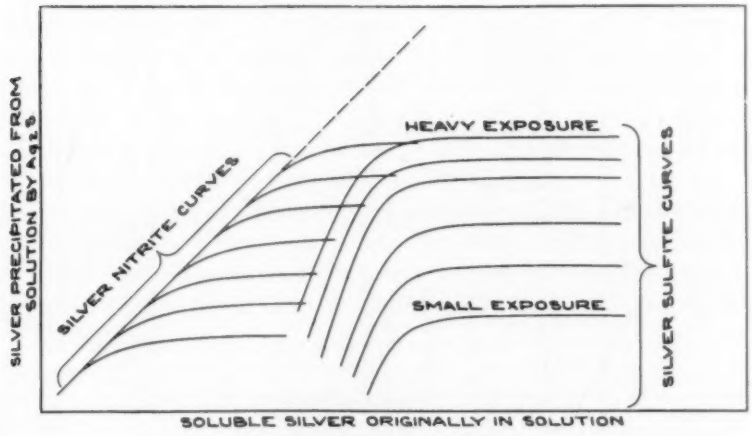
FIG. 1.



Experimental concentration curve.

Fig. 1. It will be seen that during the two minutes' exposure the whole of the silver nitrite was removed from the solution at low concentrations, whereas the sulfite was only active at above N/1000 strength. The position of these curves is evidently dependent on the degree of light exposure and a family of curves would be obtainable of the form suggested in Fig. 2. Since no data are available concerning the quantity

FIG. 2.



Theoretical concentration curves.

of light actually absorbed by the silver sulfide particles during exposure, and since these particles are being obscured progressively by metallic silver, no deduction of quantum yield can yet be made, and the apparent magnitude of the response to light has no quantitative significance. In the thickness used, the sulfide suspension had a density of about .1 at the beginning of intensification, increasing to .3 at the finish. The material is sensitive to all visible radiations and as there is little selective absorption,* it can be assumed that the particles at the back of the cell were receiving at least 90 per cent. of the light available in the front layers at the beginning of each experiment.

THE EXPOSURE-DENSITY RELATION.

A silver sulfide suspension which is quite unchecked by ordinary filter paper becomes completely filterable after an exposure which increases its weight by 50 per cent., i.e., from 2 units to 3 by the addition of one unit of silver. Such a density gain, acquired by particles whose original sizes are likely to be distributed according to a probability relation, could scarcely make even a small fraction filterable if the deposition of an external layer of silver were the only effect, and the generation of separate particles of silver is evidently ruled out of the question. The process must, therefore, be one of deposition followed by flocculation and cementation † of the particles. The aggregates continue to grow, but at any moment they may each be considered to consist of a sensitive nucleus or several nuclei surrounded by a semi-opaque wall. It would be attractive to trace the relationship between yield of silver and the opacity of this wall as exposure proceeds. The relation would hold strictly only for layers one particle thick, and it is manifest that in our experimental cells so many thousands of layers are involved that the individual particle wall becomes negligible when compared with the screening of the successive layers upon those below. It could reasonably be assumed that the yield of silver, d Ag, in any particular infinitesimal layer, n, during an interval, dt, was pro-

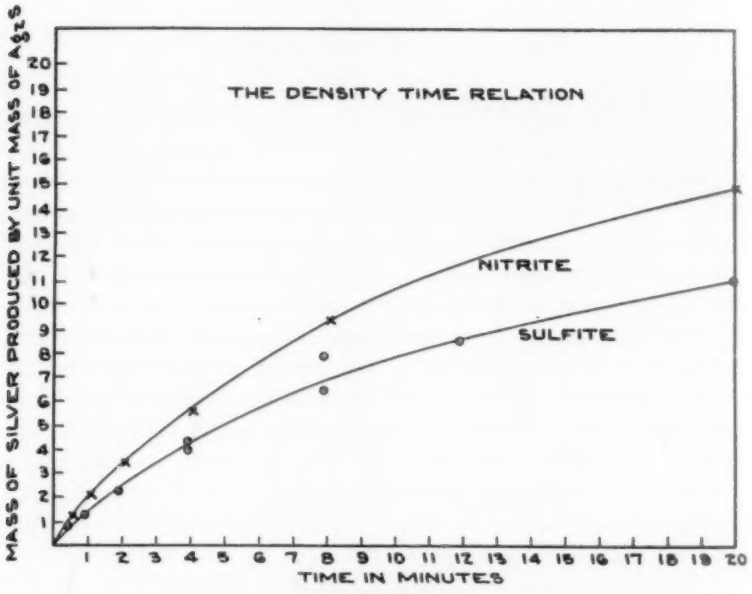
* The absorption increases towards the blue.

† An Ag2S intensifying solution subjected to a short exposure of high intensity yields a heavy, black precipitate which settles out by gravity immediately.

portional to the illumination in that layer. Since, however, we have no knowledge how the increment of mass, *d* Ag, contributes to the total density, a calculation based on the simple Density: Mass relation would have little meaning. Stated another way, as the suspended particles of Ag_2S acquire silver, their photometric constant alters till finally a stage is reached, just before precipitation, where increase in exposure may actually decrease the total opacity.

The mass-exposure relation for the nitrite and sulfite intensifiers is shown in Fig. 3. The curves are essentially of the

FIG. 3.


THE DENSITY TIME RELATION
NITRITE
SULFITE
MASS OF SILVER PRODUCED BY UNIT MASS OF Ag2S
TIME IN MINUTES
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Density-time relation.

same form, the sulfite intensifier of the composition chosen, happening to be a trifle slower than the nitrite. The form is not inconsistent with a fall in sensitivity due to obscuration of the active surface and this, taken with the fact that sulfide suspensions in gelatin layers regain their pristine sensitivity after removal of silver, strengthens the suggestion that the print-out sensitivity is fundamentally constant for any given suspension and solution throughout the duration of exposure.

SENSITIVITY AND SILVER ION CONCENTRATION.

The nitrite and sulfite intensifiers both hold the bulk of the silver in a double molecule or complex anion, and the following equilibria are likely to be established:

$$\begin{array}{ccccc} AgNO_2 + KNO_2 & \rightleftharpoons & KAg(NO_2)_2 & \rightleftharpoons & K^+ + Ag(NO_2)_2^- \\ \Updownarrow & & \Updownarrow & & \\ Ag^+ + NO_2^- & & Ag^+ + K(NO_2)_2^- & & \end{array}$$

and

$$\begin{array}{ccccc} Ag_2SO_3 + Na_2SO_3 & \rightleftharpoons & 2NaAgSO_3 & \rightleftharpoons & Na^+ + AgSO_3^- \\ \Updownarrow & & \Updownarrow & & \\ 2Ag^+ + SO_3^= & & Ag^+ + NaSO_3^- & & \end{array}$$

Among a number of possibilities, the photochemical action may involve:

(1) Ag_2S and Ag^+

(2) Ag_2S and $Ag(NO_2)_2^-$ or $AgSO_3^-$

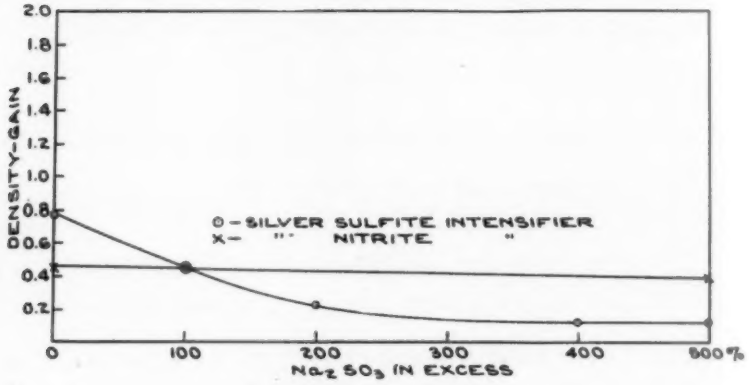
(3) Ag_2S and $KAg(NO_2)_2$ or $NaAgSO_3$.

If the first case holds, the sensitivity will be greatest for the minimum quantity of nitrite or sulfite necessary to keep the silver in solution. Any excess will depress the ionization and increase the concentration of the double molecule. The silver ion concentration will be at a stable maximum in a solution in which the single silver nitrite or sulfite is just about to deposit and will possess a greater unstable value in a supersaturated solution.

This is borne out well in the behavior of the silver sulfite intensifier. The speed of intensification is greatest when the silver sulfite is redissolved in the minimum quantity of sulfite-bisulfite solution and this speed is independent, within limits shown in Fig. 1, of the absolute concentration. The speed shows an erratic increase over the "highest" value if the solution is aerated during exposure and the increase coincides with the separation of silver sulfite crystals from the solution. Aerial oxidation removes some of the sulfite and the solution becomes supersaturated with silver. Large excesses of sulfite depress the intensification speed greatly. The complete relation between sensitivity and sulfite concentration is shown

in Fig. 4. In this figure, also, is included the curve for excess nitrite. Silver nitrite is 17,000 times more soluble in cold water than silver sulfite,[9] and since only twice as much KNO_2 is required for resolution as Na_2SO_3 is required by Ag_2SO_3, it is plain that potassium nitrite has much less complex-forming power. A very large excess scarcely impairs the sensitivity.

FIG. 4.



Sulfite and nitrite excess curves.

SENSITIVITY AND pH; THE EFFECT OF GELATIN.

When acid is added to the intensifying solutions the single silver salts are precipitated in the case of the sulfite; it is evidently only the $NaSO_3^-$ which is capable of keeping the Ag_2SO_3 in solution and free sulfurous acid has small power to form the double salt, perhaps because the acid is in the form $SO_2 \cdot x\,H_2O$ rather than H_2SO_3.[10] With the nitrite, nitrous acid is freed which liberates oxids of nitrogen, and the solution is decomposed.

Where much alkali is added to the solutions, silver oxide is precipitated, and the useful range for examining variations with pH is thus limited to pH 11.5–pH 4.8.

The variation in sensitivity over this range was found to be so small that colorimetric pH determinations were sufficiently accurate. For the sulfite determination, the pure salt from strontium sulfite was used and the acidity was ad-

TABLE II.

Ag_2S Suspension	$AgNO_3$ Soln. 2 Per cent.	Na_2SO_3 10 Per cent.	$NaHSO_3$ 10 Per cent.	NaOH N/10.	H_2O.	pH.	Photometric Reading.	Density.	Density Gain.
25 cc.	5 cc.	2 cc.	none	1 cc.	to 50 cc.	11.5	57.8	.55	.39
"	"	"	"	0.3 "	"	10.0	58.6	.60	.44
"	"	"	"	0.1 "	"	9.0	58.1	.57	.41
"	"	"	"	none	"	8.4	58.3	.58	.42
"	"	"	0.3	"	"	6.9	58.2	.57	.41
"	"	"	3.0	"	"	5.7	58.1	.57	.41
"	"	"	18.0	"	"	4.8	58.3	.58	.42

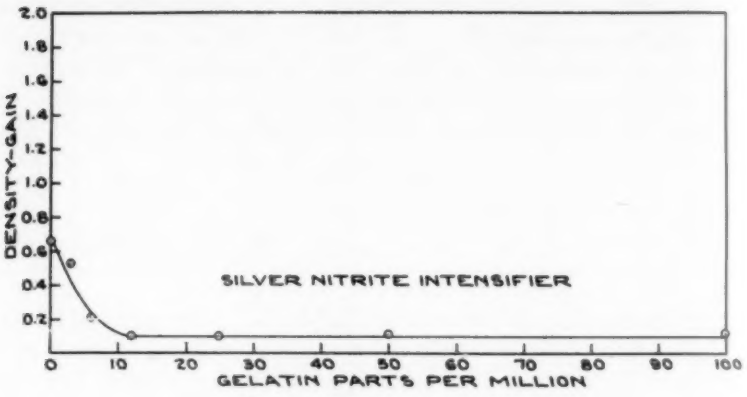
justed in the manner shown in Table II. The acidity of the nitrite series was controlled with caustic soda and acetic acid and the slight trend in sensitivity recorded in Table III was noted:

TABLE III.

Nature of Addition to 50 cc. of Solution.	pH.	Density Gain on Illumination.
.1 cc. N/10 NaOH	9.8	.36
.5 " N/100 "	9.3	.36
None	8.1	.39
.1 cc. 1/10% acetic acid	7.3	.37
.1 " 1% " "	6.2	.38
.1 " 10% " "	5.2	.48
.1 " 10% " "	5.2	.53

Gelatin added to neutral nitrite or sulfite intensifier mixtures (at pH 8 approx.) had an extremely depressing effect, which was most marked when the colloid was present during the formation of the Ag_2S suspension from silver nitrate and H_2S. The curve in Fig. 5 was secured with a solution containing 2 per cent. $NaNO_2$ and 0.2 per cent. $AgNO_3$ per litre, and varying quantities of gelatin added to the otherwise complete solution just before exposure. Uniformly reliable readings were secured with sulfite only when the gelatin was present in the original sulfite suspension. Two such suspensions were made, one to contain 20 parts per million of gelatin when finally diluted for exposure, and the other, to contain 100 parts. The proportion of gelatin to silver sulfide, weight for weight, was, thus, 20 to 73 and 100 to 73. The solutions contained .2 per cent. $AgNO_3$ and 5 times the weight of neutral sulfite. The variation of sensitivity with pH is shown in Fig.

FIG. 5.

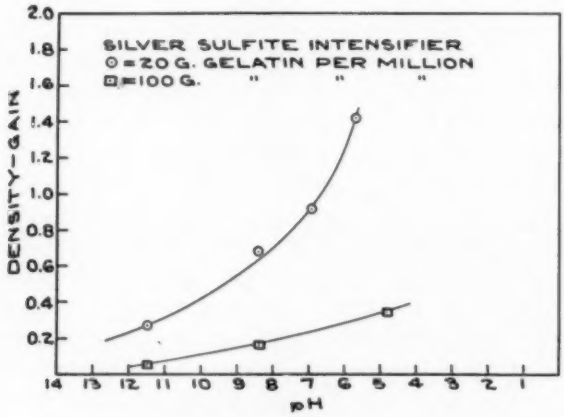


Nitrite-gelatin curve.

6. The absolute magnitude of the density gains is not comparable with those from the other experiments and, with gelatin, the speed is never as fast as in its absence.

It would be interesting to follow the sensitivity of the suspension on the acid side of the gelatin isoelectric point, but this at present cannot be done. We hazard the guess that the depression due to the colloid is at a minimum at pH 4.8.

FIG. 6.



Sulfite-gelatin curve.

THE RECIPROCITY RELATION AND THE TEMPERATURE COEFFICIENT.

(*a*) *Reciprocity.* As far as possible in the conduct of these experiments exposures completely identical in time, in distance from the light source, and in temperature condition had been given. The validity of the relation

$$E = It$$

had not been brought into question, yet there was no evidence that it holds in the present case.

A series of exposures of constant $I \times t$ with values of t varying as d^2, were now made, where d = distance from lamp. The exposures were made at 26½° C., at which temperature the spontaneous dark reaction for the sulfite intensifier was approximately .005 density unit per minute. The figures are recorded in Table IV, and the reciprocity curve is shown in

TABLE IV.

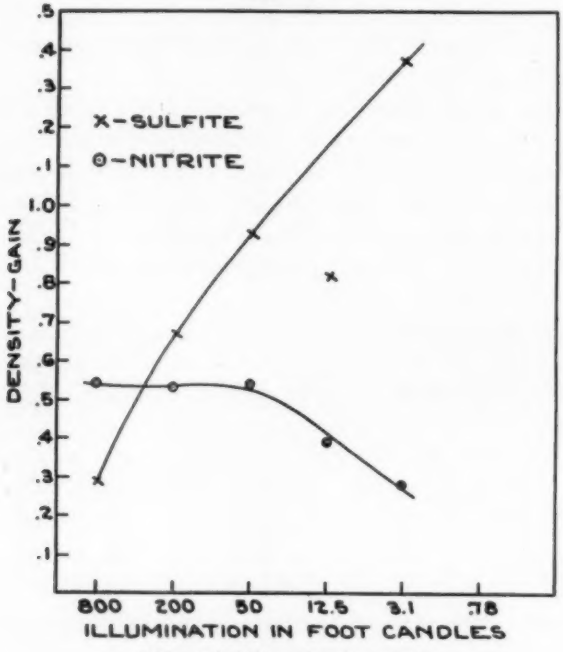
Ag_2S Suspension.	$AgNO_3$, 2 Per cent. Soln.	$NaSO_3$ 10 Per cent.	H_2O.	Distance from Lamp.	Exposure Time.	Density Gain.	Probable Dark Density Gain.	Probable Light Density Gain.
25 cc.	5 cc.	1.7 cc.	to 50 cc.	4″	1/2 min.	.29	.00	.29
"	"	"	"	8″	2 mins.	.68	.01	.67
"	"	"	"	16″	8 "	.98	.04	.94
"	"	"	"	34″	32 "	.98	.16	.82
"	"	"	"	64″	128 "	2.00	.63	1.37
"	"	"	"	Dark	128 "	.63	.63	.00

Fig. 7. The figures for the nitrite series are not given, since they are more orderly and the dark reaction was negligible (.02 unit in 128 minutes). The corresponding nitrite reciprocity curve is plotted in Fig. 7 with the sulfite curve.

The curves are strikingly different, and they evidently arise from different kinds of reaction. The density determinations for the three times 1/2 min., 2 min. and 8 min. are reliable, and the first part of each curve is, therefore, a faithful representation of how the product It alters in effectiveness with diminishing intensity and increase in exposure time. At 32 minutes, a little of the Ag_2S has settled out on the floor of the cell, and at 128 minutes perhaps half has settled. The density gain values are, therefore, too low. When the suspensions are stirred to prevent settling, it is found that the stirring hastens coagulation and that in the course of a few

minutes all the silver sulfide has collected into a few large granules. The reciprocity relation can be studied in the presence of much gelatin, but it then presents a somewhat different problem, and will accordingly be found in Part 3 of this series.

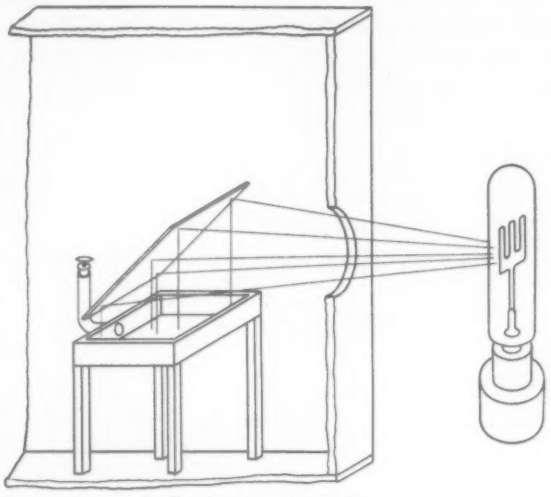
FIG. 7.



Sulfite and nitrite reciprocity curves.

The glass exposing cell was now altered and placed in a horizontal position so that the solution would present a large horizontal area and a small vertical depth. The rays from the lamp were reflected at right angles by a glass mirror. It was thought probable that except for the shortest exposures, it would matter little whether the Ag_2S remained colloidally suspended or deposited in an even layer over the cell bottom. If the opacity remained unaltered and the diffusion of salts into and away from the settled layer was rapid compared with the photochemical change, the darkening should proceed at the same rate as with the true suspension. This guess was proved, by experiment, to be correct.

FIG. 8.



Constant temperature box.

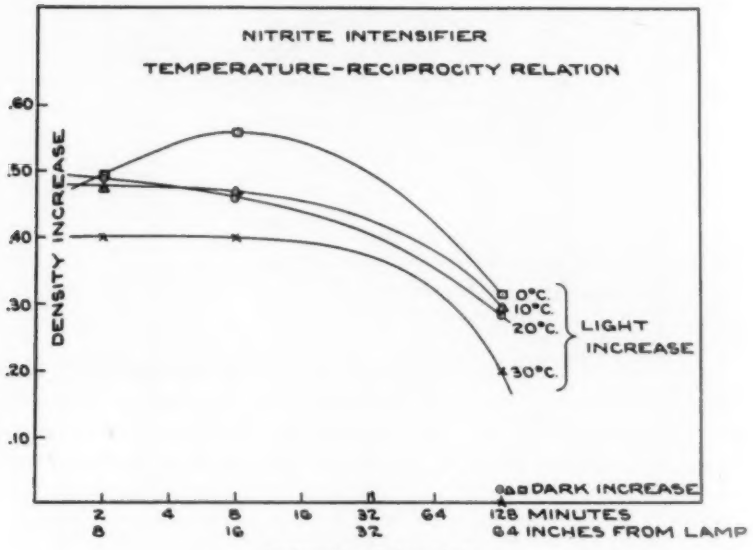
The cell and reflector were mounted in the constant temperature box (Fig. 8) and the reciprocity relation traced at various temperatures. In presenting the meager data of Table V, together with Figs. 9 and 10, it may be remarked

TABLE V.

Kind of Solution.	Temperature.	Exposure 8" from Light.	Immediate Density Gain.	Total Density Gain after 128 Mins. in Dark.	Dark Density Gain.
Nitrite.....	0° C.	0	.00	.00	.00
"	"	1/4 min.	.09	.09	.00
"	"	1/2 "	.17	.17	.00
"	"	1 "	.28	.29	.01
Sulfite.....	0° C.	0	.00	.02	.02
"	"	1/4 min.	.04	.04	.00
"	"	1/2 "	.05	.09	.04
"	"	1 "	.07	.20	.13
Nitrite.....	30° C.	0	.00	.00	.00
"	"	1/4 min.	.05	.08	−.03
"	"	1/2 "	.12	.13	+.01
"	"	1 "	.23	.21	−.02
Sulfite.....	30° C.	0	.00	1.88	1.88
"	"	1/4 min.	.07	1.99	1.92
"	"	1/2 "	.10	2.07	1.97
"	"	1 "	.16	2.33	2.17

that the few determinations, amounting to only 3 points per curve, took two months to secure and time was not available for more, but there is little doubt that the curves show the real trend of the reactions. The exact shape of the curves can be found later if needed.

FIG. 9.



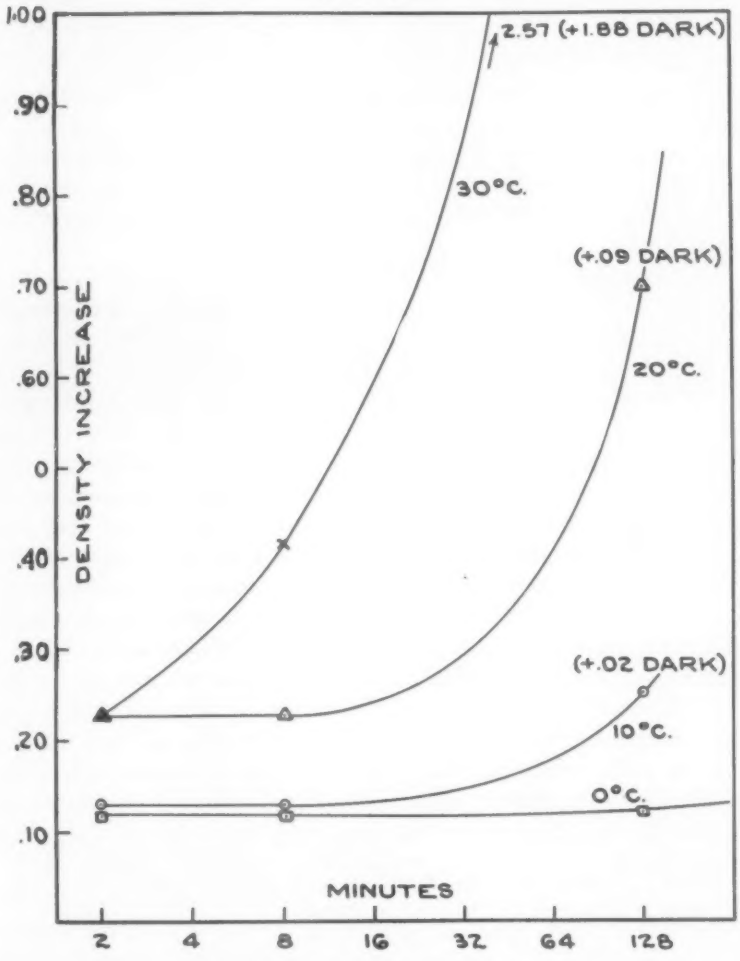
Reciprocity relation; nitrite.

The difference in the nitrite and sulfite curves can be explained fairly reasonably. The oxidation product of silver sulfite is sulfate or thionate, neither of which are oxidizing agents for metallic silver. The oxidation product of silver nitrite is nitric acid, which, at all times, and especially at the moment of formation, is a powerful solvent for silver. The by-product of light action on silver sodium nitrite, therefore, tends to dissolve up the separated silver. In support of this contention, we find that the spontaneous dark reaction, which increases so markedly with the sulfite solution with rising temperature, actually decreases with the nitrite and is, if anything, negative above 30° C.

In apparent contradiction is the gradual separation of silver on the walls of the bottle of stock solution of sodium

silver nitrite. How can there be at one and the same time a tendency to deposit and a tendency to dissolve? The difference, it would seem, lies in the conditions. In the bottle, the

FIG. 10.



Reciprocity relation; sulfite.

nitric acid corresponding to the slow deposition of silver has ample time to displace oxides of nitrogen which can attack the stopper or otherwise escape. The silver laid down on the

walls is the *net* product of the contending reduction and oxidation.

When the deposition is artificially stimulated some thousand-fold by light, the nitric acid is temporarily increased in concentration and attacks the light-liberated silver—a little in 2 minutes, considerable in 128 minutes, and more in both intervals at high temperature than at low—hence the apparently negative temperature coefficient of the nitrite light reaction.

The silver sulfite solution shows no tendency to redissolve the light-separated silver but exhibits a very marked tendency to use this silver as a nucleus for an accelerated spontaneous deposition.

This autocatalytic effect of the silver separated in earlier stages of the light reaction on the yield during later stages was examined specifically. Considering the normal exposure 2 minutes at 8 inches from the lamp, pre-exposures of 1/8, 1/4 and 1/2 this time were given to both nitrite and sulfite suspensions at 0° C. and at 30° C. to ascertain the influence on the dark reaction during the next 128 minutes. The findings, summarized in Table V, show clearly that the separated silver is without catalytic effect in nitrite solution and has a small positive action in sulfite. In the latter case it has evidently a much more powerful effect when liberated slowly by low intensity exposure during the 128-minute wait than when pre-formed. Thus, a 2-minute pre-exposure at 30° C. should, judging by the last line in the table, give a total density after 128 minutes' wait of about 2.79, but it has already been shown in Fig. 10 that the same exposure ($I \times t$) spread over the 128 minutes gives a final density of 4.55. Nascent silver, then, is a better catalyst for silver sulfite decomposition than colloidal silver.

THE COMPOSITION OF THE SEPARATED SILVER.

Mr. J. H. Hudson of this laboratory very kindly performed some microanalyses for sulfur on portions of colloidal silver sulfide solution by the methylene blue method.[11] Corresponding analyses for silver were performed by the authors by the sulfide colorimetric method generally employed throughout this work. It would appear, from the results

collected in Table VI, that the material laid down by light is metallic silver, and the proportion (1.25 equivalent Ag to .4 equivalent S) of metal added is in no direct relation to the wastage of sulfur. It was thought at first that the metal resulting from the spontaneous decomposition (dark reaction) of sodium silver sulfite at 30° C. was largely contaminated with Ag_2S, but evidently this is also pure metallic silver.

TABLE VI.

Quantity of Colloidal Sulfide Taken.	Treatment.	Silver Found.		Sulfur Found.	
		Mass.	Equivalent.	Mass.	Equivalent
25 cc.	None	.00156 g.	1	.000252	1.09
25 "	Silver sulfite soln. and exposed to light 2 min. at 8 inches.	.00352	2.25	.000156	.62
25 cc.	Silver sulfite soln. 128 min. dark at 30° C.	.0169	10.8	.000226	.90

SUMMARY.

This paper is, in itself, a summary of a large number of experimental facts, each one of which has perforce received less than its proper meed of attention. A summary of such a collection can be made only by a process of elimination, designed to give prominence to the more interesting items. Of these, the following have been chosen:

(1) Silver sulfide is sensitive to light and accumulates metallic silver when illuminated under solutions containing free silver ion.

(2) This is a general phenomenon but is exhibited best in solutions of sodium silver sulfite and of sodium silver nitrite.

(3) The yield of silver is not related stoichiometrically to the quantity of silver sulfide or the wastage of sulfur.

(4) This "photographic effect" is altered profoundly by gelatin and changes of pH.

(5) The silver sulfide is sensitive to the whole visible spectrum, and far into the infra-red.

(6) There is a marked reciprocity failure which differs in direction and degree for the sulfite and nitrite solutions.

(7) The effect in nitrite solution shows an apparent negative thermal coefficient.

(8) The mechanism of the reaction in nitrite solution is thought to be relatively simple; that in sulfite solution is known to be complex.

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THE BRANCHING OF LIGHTNING AND THE POLARITY OF THUNDERCLOUDS.

BY

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Since the beginning of the twentieth century many investigations bearing on the origin of the electricity in the thundercloud, its sign, distribution and quantity, the motion of air currents within the cloud, the charges brought down by falling rain, and the magnitude and direction of the sudden potential changes induced by lightning discharges have been made. Researches in this field have been increasingly numerous during the last twenty years.

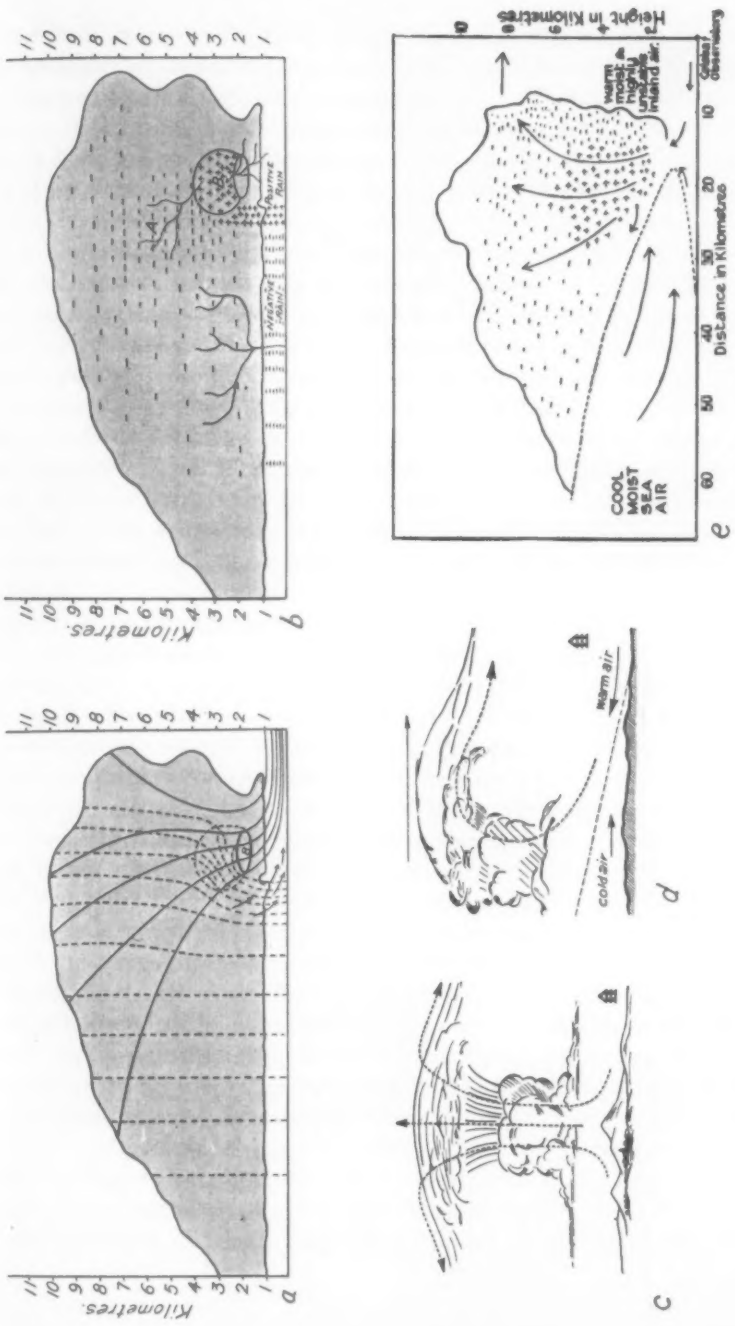
The "breaking-drop" theory of Simpson (1) provided the first satisfactory working hypothesis for accounting for the origin of the electric charges in the thundercloud. It was based on laboratory experiments which show that when a drop of water is broken up in the air, the drop obtains a positive charge and the air a negative one. Meteorological data accumulated during extended investigations at Simla, India, were employed to substantiate his theory which requires that rain from the active part of a thundercloud, where there are rapid convection currents, should be positively charged, while that from the posterior portion of the cloud should carry down negative electricity. An application of Simpson's theory to meteorological conditions in the United States, together with much supplementary information regarding thunderstorms, has been prepared by Humphreys (2).

In 1926 Simpson (3) made a study of the electrostatic field within and below an ideal charged cloud-mass of spherical form, and showed that the field of greatest stress will be between the lower charge and the earth and that the beginning of the discharge path will occur in this region of high potential gradient. Once the discharge begins, ions from the adjacent atmosphere will drain into the conducting channel and cause

partial collapse of the field as the channel proceeds towards the earth. He maintained, on the basis of experiments with discharges from a large Wimshurst machine, that if positive electricity is passing to earth the higher mobility of negative ions will result in straight and thin channels with lateral branchings, while if this downward discharge is negative there should result a larger, more diffused channel, without branching. These principles were applied to 442 photographs of lightning obtained from various sources. 242, or 54 per cent., showed branching away from the cloud, indicating, according to his theory, that it was positively charged, while in only three was there branching up into a negative cloud. There were 173 in which no branching was discernible and the remainder were listed as meandering and unclassified. Since many of those with no visible branches probably would have shown them except for the dimming effects of rain between the discharge and the camera, this was considered positive proof that most lightning discharges which strike the earth proceed from a cloud whose lower portion has a positive charge.

In two later papers (4, 5) Simpson has attempted to show that the observational data collected by some other investigators are, in fact, in agreement with his breaking-drop theory. In Fig. 1*a* is reproduced his diagram showing the stream lines of air coming from the right and ascending into the active part of the cloud where their upward components exceed the critical speed of 8 meters per second required by the breaking-drop theory. Here the largest drops become unstable and break up, with corresponding positive charges on the larger of the resulting droplets. The smaller negative drops are carried upward and distributed laterally. Fig. 1*b* shows the resulting distribution of charges, the region of maximum upward air currents being characterized by a concentration of positive electricity, and the corresponding negative being scattered through more space. Discharges are divided into three principal groups—Type U, upward discharges from the head of the positive ascending currents; Type D, downward from the same region; and Type N, discharges from the ground to negative cloud areas. The large number from one part of the cloud to another, or to adjoining clouds, are not considered.

FIG. 1.


Kilometres.
Height in Kilometres
Distance in Kilometres
COOL MOIST SEA AIR
warm moist unstable inland air
warm air
cold air
a
b
c
d
e

In two recent papers Banerji (6, 7), has given the most complete meteorological and electrical data on thunderstorms thus far published. By use of a combination of self-recording and other instruments he has recorded the humidity, barometric pressure, temperature, wind direction and velocity, rate of rainfall, sign and magnitude of the potential gradient, and nature of the sudden field changes connected with lightning discharges, during the passage of 41 storms. His diagram of a "heat" thunderstorm differs from that of Simpson shown in Fig. 1*b* only in having negative charges of considerable intensity distributed in the anterior part of the cloud as well as in the upper and posterior portions. Fig. 1*e* is a reproduction of his diagram of a "line-squall" thunderstorm in which the direction of ascending air currents and the distribution of electrical charges is very similar to Simpson's in Fig. 1*b*. Banerji observed storms of single and of double type, the latter producing the same effect as two single storms following each other. In the typical single storm the potential gradient, taken upward, was first strongly negative. As the active part of the cloud came overhead it changed to a strong positive, becoming negative again as the storm passed on. The altitude of the clouds at Bombay is such that lightning is very seldom seen to strike the ground.

As an explanation of the process by which the moisture-laden air in the ascending column may become highly charged and the existing electrical field augmented, Toepler expressed a preference for the influence-machine action proposed by Elster and Geitel, (9) (11, p. 135), over the Simpson breaking-drop theory. This requires that the larger drops have induced charges of opposite sign on their upper and lower surfaces and that the smaller droplets shall carry up with them the charges gained by contact with the lower hemispheres of the falling drops. The result would be an increase in the potential gradient, for if the gradient were negative upward these charges from the lower part of the drops would be negative and their loss would leave the drops themselves with a positive charge. However, such an initial field is contrary in its direction to the normal fair-weather field. Toepler also emphasizes the importance of the ionizing power of the ultra-violet in the lightning flash in maintaining a

supply of charged droplets. In this connection attention is also called to an experiment of Nukiyama and Noto (10) in which a water-dropper, connected to an electrometer was exposed to ultra-violet light from an arc, which caused the charges collected to change from positive to negative. Figure 1*d* represents the process by which, according to Toepler, a "heat" thunderstorm may develop into the "cold-front" type. Such a storm would have an overhanging, negatively charged front similar to the line-squall model of Banerji although no provision is made for a negative region in its posterior section. Toepler calls attention to the fact that the accumulated totals of various observers, obtained by placing magnetisable material near lightning conductors, favor discharges from earth-to-cloud over cloud-to-earth in the ratio of 103 to 46. His cloud models with lower pole positive should give a majority of cloud-to-earth flashes. He accounts for the discrepancy on the ground that in positive discharges there is so much branching that the current in any one of the many channels is not sufficient to produce the required magnetic effect. This viewpoint is also held by Watt (11).

C. T. R. Wilson (12, 13), basing his conclusions on measurements of potential gradients below storm clouds, the electric moments of their charges, and the sudden changes in the direction of the gradient following a lightning discharge, came to the conclusion that thunder clouds are bipolar in form. His lightning discharge records indicate that more that 60 per cent. of them came from clouds with lower pole negative. Wilson also applied well-known principles of gaseous ionization at reduced pressures to show that a cloud with positive upper pole is more probable than the converse condition. He assumes two bipolar clouds, one with upper potential at $+ V_2$ and lower pole $- V_1$, and another whose upper potential is $- V_1'$ and lower potential $+ V_2'$. The clouds are similar generators such that $V_2 - V_1 = V_2' - V_1'$. The one with positive upper pole should attract free electrons from the upper atmosphere while its companion can attract only slow-moving positive ions, resulting in a much lower effective resistance between the positive cloud and the conducting layer. The negative lower pole of such a cloud should in turn attract more positive ions from the ground than could the other type,

thus causing a larger total current from earth to the upper atmosphere than would flow from the cloud with upper pole negative. He also contends that more positively charged rain should fall from a cloud of positive polarity than from one of negative polarity which is in agreement with the work of Simpson already cited.

In 1927, Schonland and Craib (14), using apparatus similar to that employed by Wilson, found that practically all the 23 South African storms observed were bipolar with positive upper pole. They also established the important fact that the change in the potential gradient resulting from a lightning discharge undergoes a reversal at a distance depending on the height of the poles of the cloud. This reversal distance is found to be from 6 to 8 km. at Cape Town but at tropical latitudes, where clouds form at greater altitudes, it is considerably more. In two later papers Schonland (15) produced additional evidence in support of his contention that the upper pole of thunder clouds is usually positive. The first of these is a continuation of the experiments of Schonland and Craib with the same equipment and essentially similar conclusions. In the second experiment the current escaping from an insulated bush to an overhead cloud was measured and its direction determined. For the average cloud it amounted to 2.1 amperes in such a direction as to carry a negative charge to the earth. Wormell (16) used the same method with similar results at Cambridge, England.

Authorities differ in regard to the field changes to be expected at a given position of the observer if the discharges are within the cloud, but there is one case on which all agree, viz. discharges in either direction between the cloud and the earth. For example, Simpson (4, p. 393), divides his downward discharges into two sub-types, D_1 and D_2, according to whether they reach the ground or not. He states that all of Type D_1 must give negative changes of field regardless of how far or near the discharges may be. Type D_2 (positive discharges which do not reach the earth), however, may produce either positive or negative changes, even without change of distance, depending on the cloud height. His Type N (from earth to negative cloud) should always produce positive changes of the field. Schonland (15, p. 236), after discussing discharges

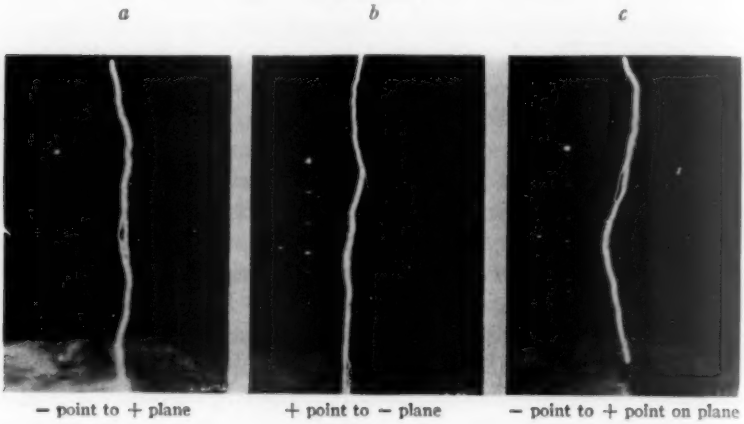
between the poles of his typical cloud with upper pole positive, states that discharges between the lower pole and the ground should result in positive field changes. A like conclusion is reached by Simon (17) after careful analysis, and by Noto (18) who used a galvanometer system similar to that employed in this experiment.

Extensive studies on lightning strokes to power transmission lines have recently been reported by electrical engineers using klydonographs, oscillographs, and other recording instruments. Thus Peek (19) states that in the many measurements of line surges made, those showing very low voltages, necessarily induced, were largely positive, as would result from a negative cloud. Most of the very high voltages, which were probably due to direct strokes, were negative, and therefore also came from negative clouds. Lewis and Foust (20), in summarizing their own results and those of other engineers, state that approximately 100 records of direct lightning strokes to transmission-line towers have been obtained. In every case the tower top was negative with respect to the tower base, as shown by the Lichtenberg figures, indicating a negative discharge from cloud to earth. They believe that in the cases where positive strokes do occur the extensive branching into streamers results in so much attenuation that the discharge may be unable to operate the lightning stroke recorder. Similar findings relative to strokes to transmission lines have been reported by Sporn and Loyd (21), Smeloff and Price (22), and by Fortescue (23).

Schonland and Allibone (24), in 1931 obtained branching from a negative point towards a positive grounded plane using an impulse generator capable of supplying 10^6 volts. Ten correlated photographs showing downward branching from negatively charged clouds are also reported. Halliday (25), using the Schonland apparatus at Johannesburg, also reports ten flashes to ground with downward branching and positive field changes, and none with negative field changes. According to Fortescue (23, p. 29), experiments carried out by Torok in the Trafford laboratories of the Westinghouse Electric Company have resulted in branching streamers issuing from both positive and negative electrodes. In Fig. 2 are reproduced three photographs made in the high-tension laboratories

of the General Electric Company and shown through the courtesy of Mr. F. W. Peek, Jr. The first, (*a*), represents a discharge from a negative point to a positive, grounded plane. In (*b*) is shown a positive discharge from an overhead point to a negative grounded plane. The branches are longer and more numerous than in (*a*) and show a tendency to subdivide. In (*c*) a negative discharge is seen to strike from an overhead point to a point on the positive, grounded plane. Three

FIG. 2.



short branches extend downward from the negative point, and one, considerably longer, runs upwards from the positive point.

RECAPITULATION.

There is obviously distinct disagreement on the part of the two groups of investigators regarding the form of the thundercloud and the distribution of charges within it. Simpson, Humphreys, Banerji, and Toepler have proposed a cloud with massed positive charges in its lower anterior part where there are active, upward convection currents. Above, in front, and to the rear of this positive region are less concentrated negative charges. Wilson, Schonland and Craib, Halliday, and Wormell, on the other hand, have accumulated many original data showing a preponderance of discharges, or convection currents, coming from a bipolar cloud with lower pole negative. This is fortified by the electrical engineers who

report that almost all direct hits to transmission lines come from negatively charged clouds. Simpson's criterion for determining the polarity of a cloud by the direction of branching of discharges coming from it has been disputed by Schonland and Allibone, and by Halliday. Independent laboratory experiments by Allibone, Peek and Torok have all resulted in obtaining streamers with branches away from the negative pole as well as from the positive.

SCOPE OF THIS INVESTIGATION.

The phenomena connected with lightning discharges have been studied by the present writer for several years and a number of progress reports have been published (26, 27). The earlier studies were concerned with the magnitude and sign of charge on falling raindrops and with the direction of field changes resulting from discharges.

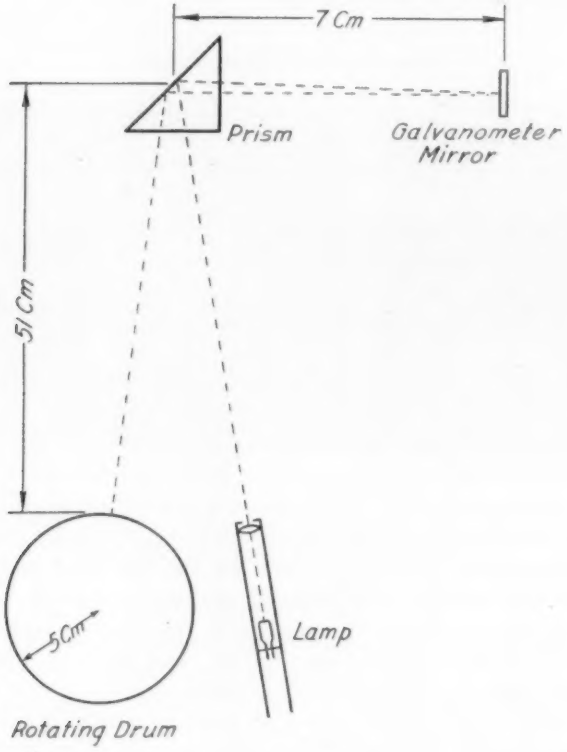
In the present investigation the problems relative to polarity of clouds and to the direction of field change resulting from a given lightning discharge, as presented in the reports of Simpson (4, 5), and of Schonland, have been studied. Data have been obtained regarding the path of the storm cloud, the portion of the cloud from which observed discharges came, their distance from the observer, and the direction of field changes they produced. The direction of branching has been observed for several types of discharges by means of numerous photographs. In view of the important bearing on polarity of clouds which attaches to *discharges which strike the ground*, as shown above (p. 712), and because such discharges are more frequent in Lincoln than in Bombay or Cape Town, they have been given special attention.

Evidence will be presented to corroborate the findings of Schonland, Halliday, and American engineers regarding the direction of branching. A differentiation will be made regarding the nature of branching in streamers from negative as compared to those from positive clouds, and a reconciliation of the various proposed cloud-types and the distribution of electricity within them with experimental data will be attempted.

APPARATUS USED.

The electrical equipment used in these experiments was comparatively simple. A Leeds & Northrup high-sensitivity galvanometer was fitted with a straight-filament lamp and right-angle prism in such a way that the image of the filament

FIG. 3.

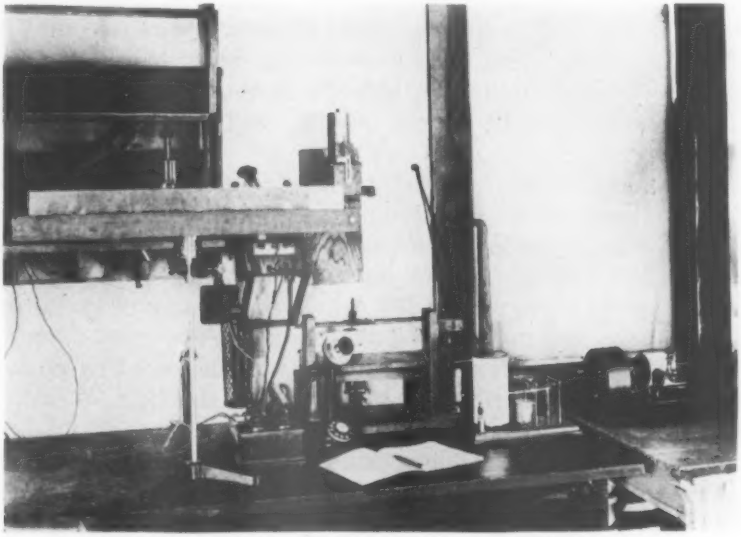


was thrown on the upper surface of a revolving cylinder, Fig. 3. The cylinder was rotated about once in twenty minutes by means of a kymograph clock and speed-reducing gears, Fig. 4. Two smooth, parallel rods served as guides for a holder carrying a pencil which the observer kept directly over the beam of light from the galvanometer, making the record semi-automatic. The ballistic sensitivity of the galvanometer as

mounted, with an optical path of 58 cm. from the mirror to the record sheet on the cylinder, was .00537 microcoulomb per mm. when undamped. For most of the observational work shunts of 4 or 9 ohms were used to reduce the sensitivity. The sensitivity with the 9 ohm shunt was .0413, and with the 4 ohm shunt, .0855 microcoulomb per mm. Its period with the 4 ohm shunt was approximately two seconds.

Four types of insulated conductors, the induced charges on which could be measured, were employed. The one most

FIG. 4.



used was a metal deck consisting of sheets of galvanized iron on a wooden frame-work. Its dimensions were 3 by 4 meters and the average height above the ground 9 meters, it being mounted on the gently-sloping roof of the gymnasium which is adjacent to the physics building. The insulation between the deck and the roof consisted of double sets of high-tension glass insulators and the wire connecting with the laboratory was carried through the wall by means of a glass tube. Adjoining the metal deck was a wire rectangle of the same dimensions as the deck and with identical insulation. An insulated ball

of general construction similar to that described by Wilson (12) was mounted on the roof of the two-story physics building. When the ball was raised from its grounded metal case on the roof it was 8 meters above the earth and about two and one-half meters above the roof. The insulation consisted of amber, sulphur, and pieces of quartz tubing. The fourth inductor consisted of a radio antenna wire 7 meters long and 1 meter above the roof. It was carefully insulated at the ends and provided at the center with an ionium collector. Careful measurements by the loss-of-charge method showed the insulation resistance of the deck to be 3.32×10^{10} ohms, and that of the wire rectangle 1.36×10^{10} ohms, when dry. After a driving rain the resistance would drop as low as 10^6 ohms in both instances. The capacities of the deck, rectangle, and ball, as determined by the writer's method of finding small capacities (28), were .0013, .00073, and .00042 mfd., respectively.

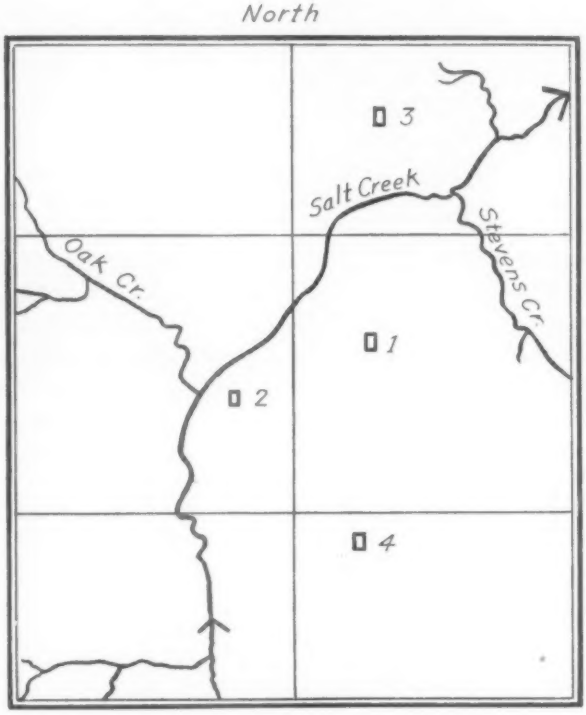
For purposes of checking on the direction of deflection of the galvanometer when a charge of a given sign was on one of the collectors, a quadrant electrometer of low sensitivity was mounted by the side of the galvanometer. A switching system provided easy means for connecting either of these instruments to any one of the four inductors.

The rate at which rain was falling was measured by means of a standard tipping-bucket rain-gauge of the U. S. Weather Bureau type.

Because of the importance attached by most of the investigators to knowing definitely whether the active part of a cloud had passed overhead, four Tycos microbarographs were secured. These were arranged with three in a north-and-south row nine and one-half miles long with the laboratory in the middle, the fourth being located at the U. S. Weather Bureau office in Lincoln, four and one-half miles south-west of the laboratory, Fig. 5. Should the west and laboratory barographs register large pressure-changes as the storm passed over, and those to the north and south show smaller changes, the center of the storm must have passed over the observer. Larger pressure changes to the south and lesser ones to the north would indicate a southeasterly course for the storm, etc. The instruments also gave valuable information re-

lating to the maximum pressure variations in each storm, their coincidence with the approach of the rush of cold air in the cloud-front, and the size and velocity of the storm area. These last items are being further investigated with the baro-

FIG. 5.



Barograph Station Map
1. Nebraska Wesleyan University
2. U. S. Weather Bureau Office
3. Parrot Farm
4. Union College

graphs distributed on a 30 mile north-and-south front and a 22 mile east-and-west line.

For photographing the lightning discharges several different kinds of cameras were tried, including a Sept motion-picture camera as described by Parkinson (29). The best pictures were obtained with a 5 × 7 Graflex camera fitted

with a B. & L. Tessar lens, rated at f 4.5 but usually operated at f 5.6. An Eastman kodak with an f 6.3 anastigmat lens also gave good results.

EXPERIMENTAL PROCEDURE.

More than nine-tenths of the field-change readings connected with lightning discharges were taken with the metal deck and the high-sensitivity galvanometer. The wire rectangle, with half the capacity of the deck, gave ballistic throws half as large as those from the deck according to the relation, $Q = CV = kd$, where k is the ballistic constant of the instrument and d the scale deflection. However, the drift of the galvanometer caused by charges on the falling raindrops should be much greater on the deck than on the rectangle. The direction of the galvanometer drift when connection was switched from deck to rectangle indicated at once the sign of the charge on the falling rain. The ball was designed to give potential gradient readings when used in connection with the electrometer. Some preliminary work of this kind was done but the location of the laboratory, with a metal smoke stack 100 ft. high, and tall trees and buildings near by, distorted the local field so that such measurements were of little value. The ionium dropper, antenna system and the electrometer served as a valuable check on the galvanometer for getting the sign of the steady field and the sudden field changes.

Since so much depends on the interpretation given to the connection between a galvanometer throw in a given direction and the corresponding field change, it is desirable to state clearly the assumptions made and the authority for making them. The insulated metal deck was connected by a copper wire to ground through the galvanometer. A negatively charged cloud overhead should attract a positive charge through the galvanometer to the deck, and vice versa. If part of this lower, negative charge escaped from cloud to earth, or an equivalent positive charge went from earth to cloud, the bound positive charge on the deck should be released, causing a ballistic throw of the galvanometer as it went to ground. This procedure was carefully checked and verified by means of laboratory experiments with a Toepler-Holz machine and artificial clouds made from metal plates.

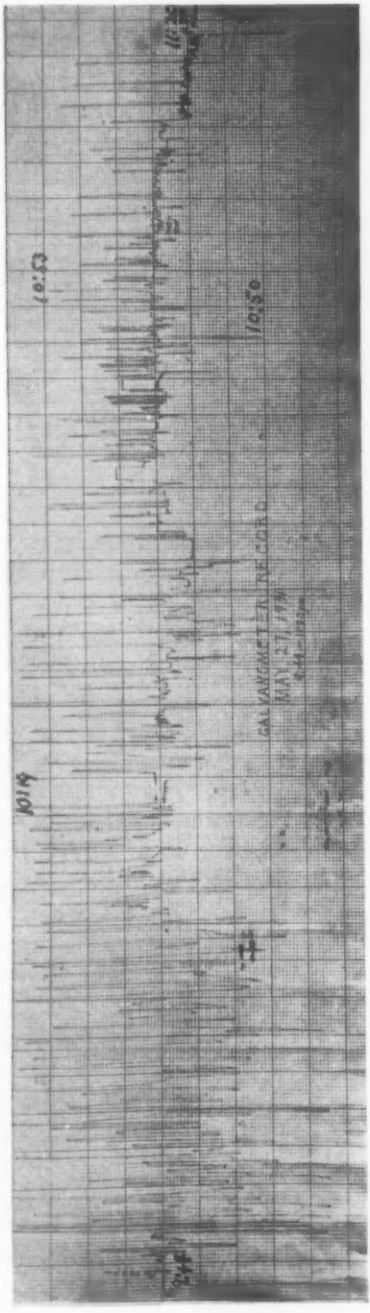


FIG. 6.

A specimen of the galvanometer records is shown in Fig. 6. It covers the period from 9:44 to 11:20 P.M. on May 27, 1931, and contains three of the record sheets used on the revolving drum. It has been greatly reduced in copying, the larger squares being one inch in the original. Each of the straight lines to left or right is the record of one lightning discharge. Throws to left (upper side of sheet) are caused by positive electricity going from deck to ground, such as would result from discharging a negatively charged cloud, i.e. a positive change in the potential gradient. Throws to right (lower side of sheet) show a negative change in the potential gradient. It will be noted that for the first ten or twelve minutes after the storm began there were nearly as many negative changes as positive. After twenty minutes the negative changes had almost ceased, and for the remainder of the storm positive changes were much the more frequent.

The use of the microbarographs in determining the path of the storm, the magnitude of pressure changes and related phenomena may best be illustrated by the use of typical examples. In Fig. 7 are shown the barograph records of a series of storms beginning on the afternoon of June 20, 1931. A dust and rain storm of the "line-squall" type as described by Humphreys (30) with northerly winds of 35 miles per hour maximum velocity began at 4:30 P.M. Heavy rain with northeast winds continued until 6:30, with lighter showers until 7:40. At 8:00 P.M. heavy thunderclouds with much lightning were visible in the south. Another storm began at 12:30 A.M., lightning getting within two miles at 12:37. This third disturbance moved slowly, with little rain, a picture at 4 miles being obtained at 1:29 A.M. The barometric changes registered on the north instrument at 12:00 to 2:00 A.M. were considerably less than on the other three, indicating that this was a minor, local storm going towards the southeast.

Figure 8, the records for May 28, 1930, tell a somewhat similar, but briefer story. The first sharp depression at 2 to 2:30 A.M. was most marked on the west and laboratory instruments and therefore passed directly overhead. The next one, beginning at 3:20 shows a much deeper depression to north than to south and passed in a northeasterly direction down Salt Creek valley, Fig. 6, a rather common occurrence.

FIG. 7.

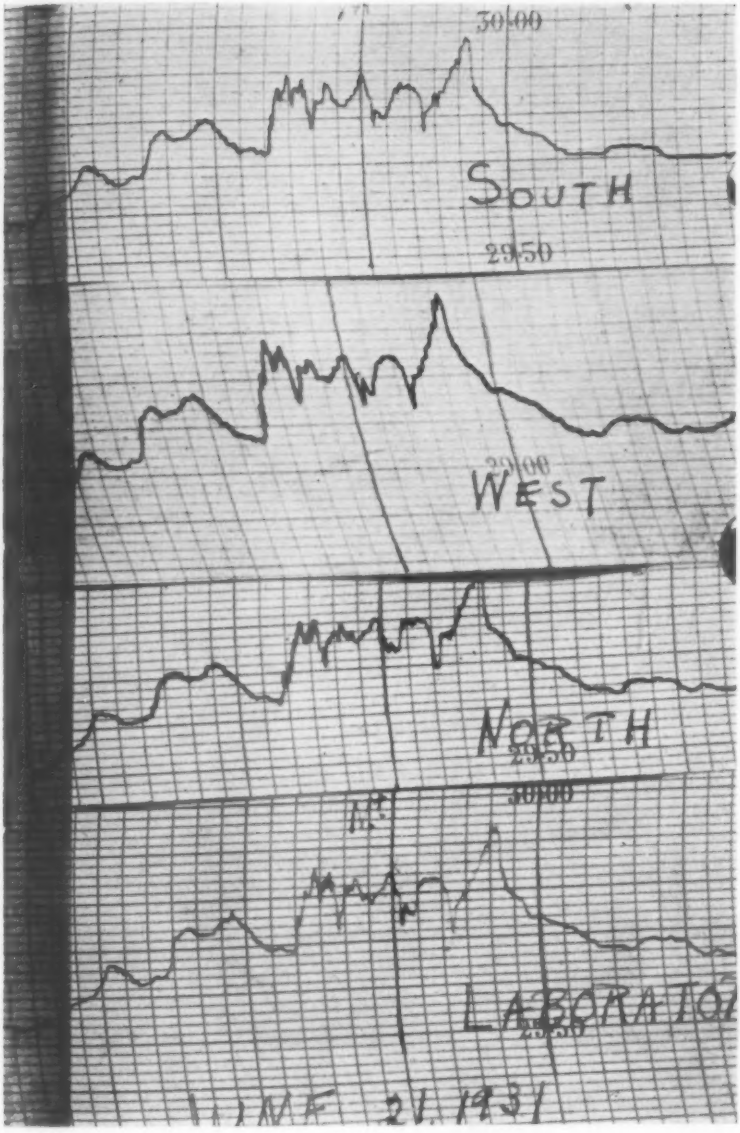


FIG. 8.

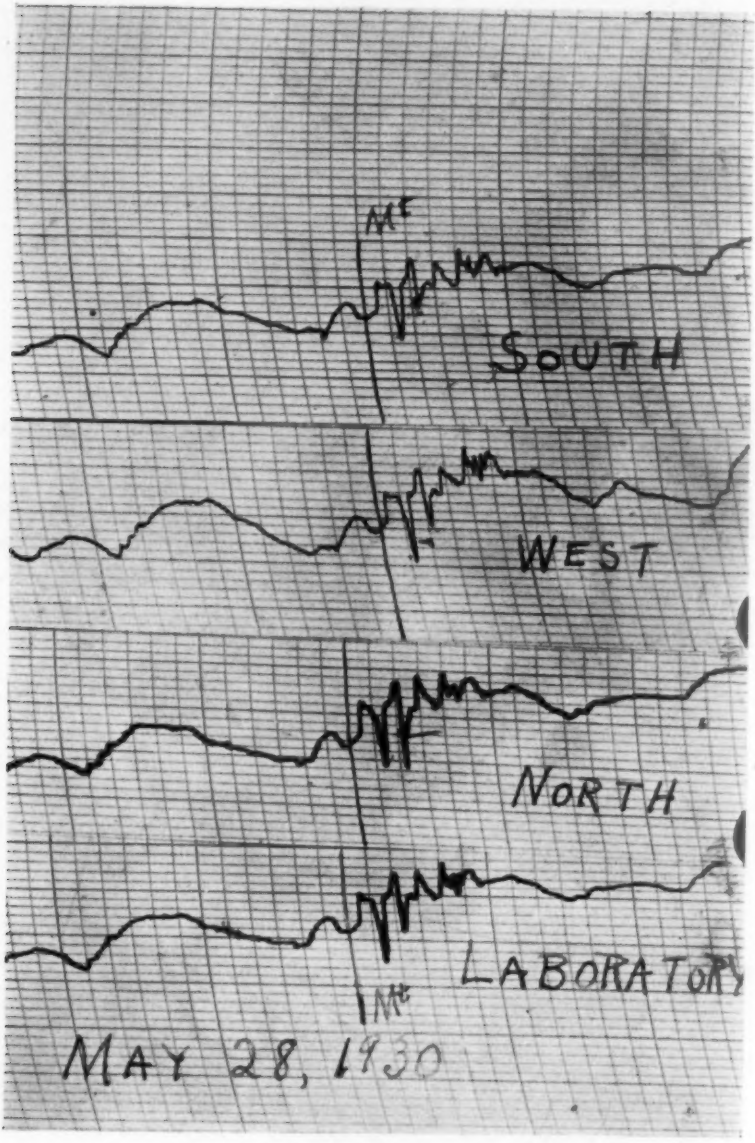
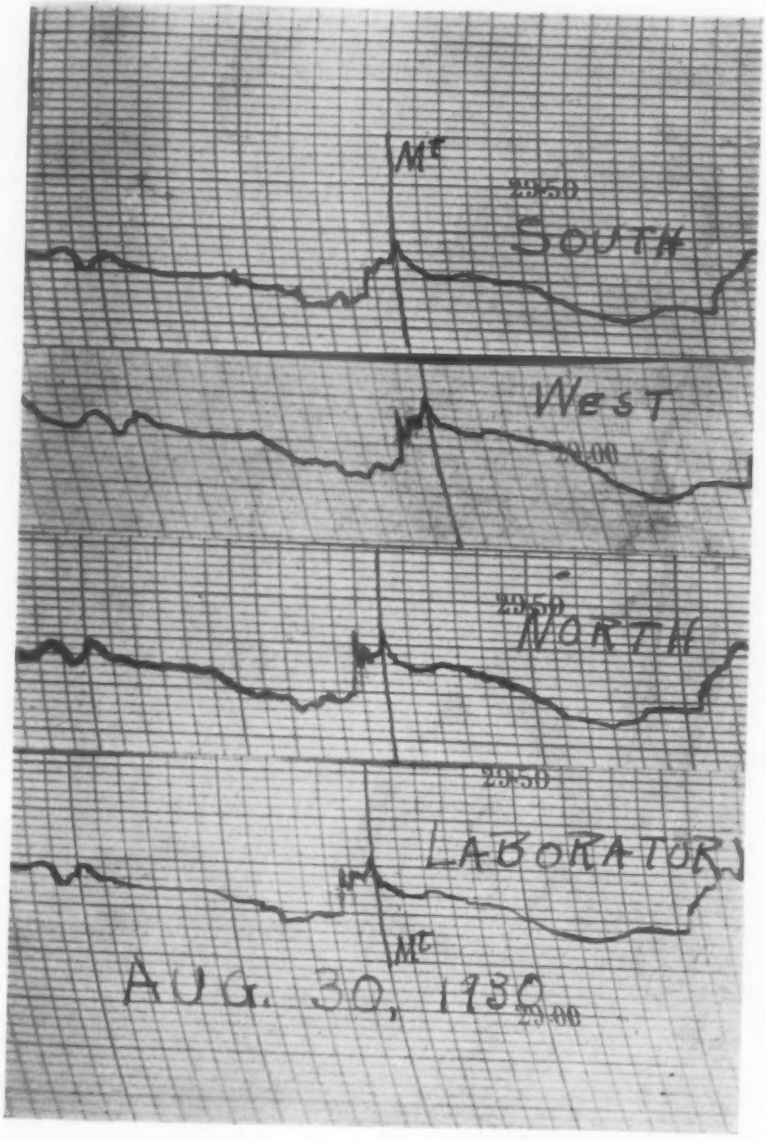


FIG. 9.


M
29·50
SOUTH
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29·00
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NORTH
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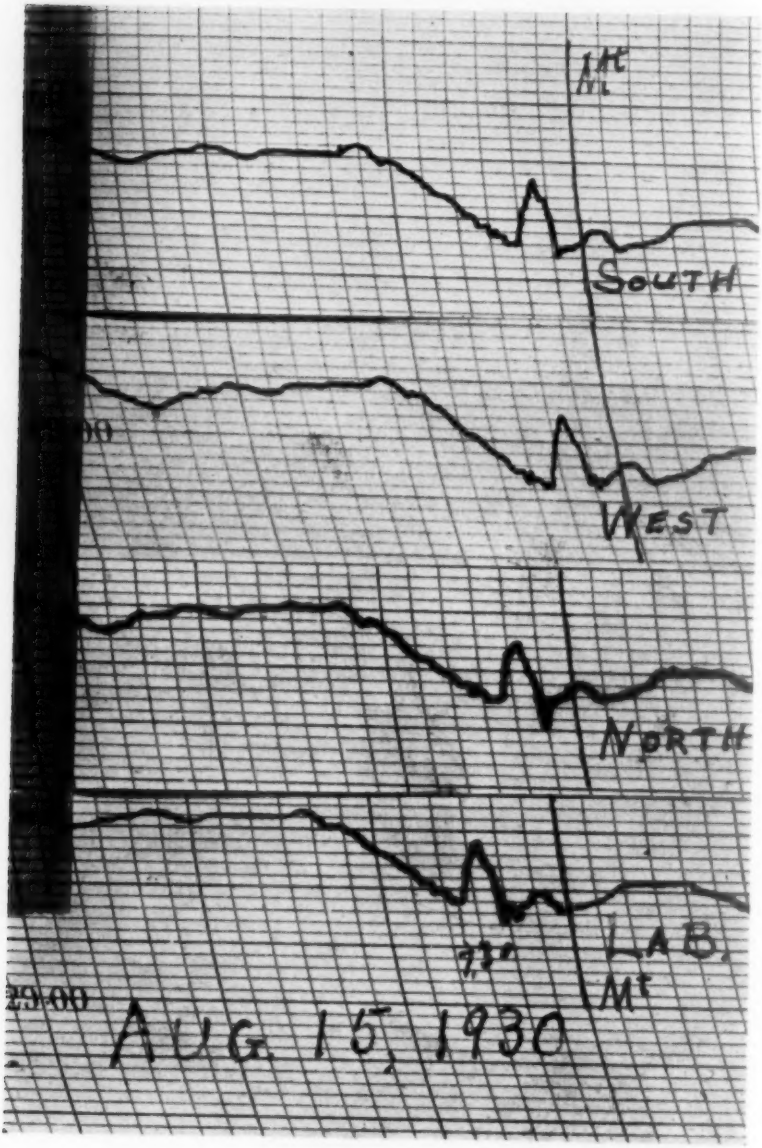
LABORATORY
M
AUG. 30, 1730
29·00

FIG. 10.



High northwest winds were recorded at 1:15 and again at 2:45 to 3:10.

The storm of August 30, 1930, the barographic record of which is given in Fig. 9, was the most prolific yet encountered for getting good pictures. Its first center passed not far to the north of the laboratory for the south instrument showed a much smaller pressure change. It had many of the characteristics of the "double" storms described by Banerji. A typical "heat" thunderstorm is illustrated in Fig. 10 with the first rush of cold air at 7:30 P.M. The barometer rose rapidly with heavy lightning overhead by 7:55. In connection with the second depression auxiliary storms developed from 9:30 to 10 o'clock. The one to the south was very active but about 10 miles away; a smaller disturbance was central between the laboratory and the north station. Very long horizontal flashes extended from the overhead storm towards that to the southward.

PHOTOGRAPHS.

In obtaining lightning photographs two observers were always needed. The pictures were taken at night from the fourth floor windows of "Main Building" which gave an unobstructed view to the west, northwest, and south. The photographer and the other observer, who remained in the physics laboratory with the galvanometer, raingauge, microbarograph, and other equipment, were in constant telephone communication over a private line. This line terminated in 100 feet of extension cord so that cameras could be moved from west to north or south windows as the storm passed over. At the instant when a flash was seen in the field of the camera the photographer called "down," or "across," giving the time and the picture number, which were at once entered on the discharge line of the galvanometer throw made by that discharge. The camera shutter was closed and a stop-watch started to get the approximate cloud distance by the interval until the resulting thunder-clap. The time, picture-number and explanatory notes were entered in the photographer's notebook before the next picture was attempted. Before developing, the films were carefully marked with an identification number.

FIG. 11.

a

b

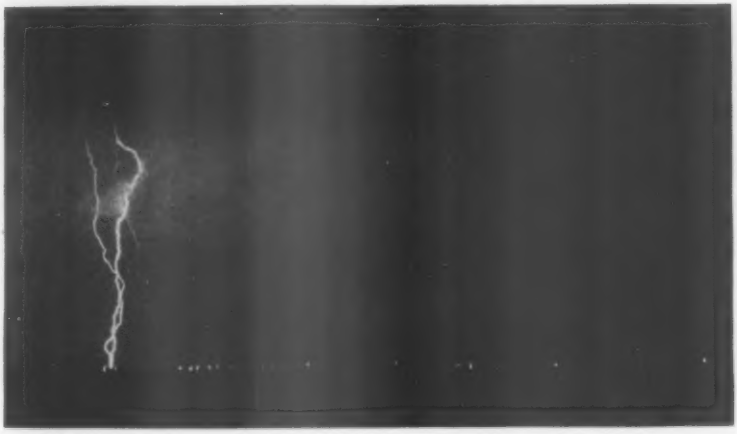
c

A lightning photograph may give significant information in addition to the direction of branching and the change in potential gradient accompanying the discharge. It is equally important to know the part of the storm from which it came

and its direction and distance from the observer. The following specimens are analyzed in detail to bring out the correlated meteorological conditions.

The pictures in Fig. 11 *a*, *b*, *c*, were taken at 9:47½, 9:48½, and 9:50 P.M., May 17, 1931. The barograph record showed that the storm from which they came passed from the northwest to the southeast, its center being 3 or 4 miles south of the observer. They were taken about 8 minutes after rain began to fall, at a distance of 3 miles, and were accompanied by large positive field changes such as would result from a negatively charged cloud discharging to earth. Figure 12 was taken from

FIG. 12.



the same cloud at 10:10 P.M. It produced a negative field change of small magnitude and has the multiple branching characteristic of a positive discharge from cloud to earth. Such a combination, first a negative and then a positive discharge, is exactly what one would expect if he were observing from the side at a short distance such a cloud as that pictured by Banerji in Fig. 1*e*. It could also be expected from the cloud of Toepler in Fig. 1*d*, but no heavy negative discharge to earth could be expected from the front of Simpson's model cloud in Fig. 1*b*.

In Fig. 13 we have another negative discharge from the

FIG. 13.

FIG. 14.

side of a cloud at 3 miles. It was taken on June 21, 1931, at 1:03 A.M. A little earlier in the same storm, at 12:40 A.M., the interesting branched discharges of Fig. 14 were caught by the camera. The galvanometer gave a sharp throw to left, indicating a positive change in the field. From the diffused nature of the branching the cloud must have been positively charged. The stopwatch time on this discharge was 10 seconds, which brings it into agreement with Simpson's type D_2, at a height of less than 2 km.

The problems involved in identification of a discharge with a galvanometer throw are well exemplified in Fig. 15 made at 10:28 P.M., May 27, 1931. Another negative discharge, throwing the galvanometer off-scale, had been photographed at 10:27. Between this and the one recorded at 10:28, which again threw the galvanometer off-scale, is a small negative field change (positive cloud), probably caused by the ribbon-like discharges on the left of the picture. The time interval of 8 seconds shows that the flash was very near by and the observer's notes made immediately after the exposure definitely identify the middle flash as the one belonging to the galvanometer throw. Had it belonged to the lighter discharge on the right of the picture it would not affect the interpretation so far as the direction of branching is concerned. Attention is directed to an interesting picture, Fig. 16. caught at 10:41 P.M. as this storm was directly overhead, The wind was blowing 43 miles per hour from the southwest and heavy rain was falling. Its main channel consists of 3 or 4 parallel streaks and the long streamers are strongly reversed, indicating unmistakably that a succession of discharges took place. The discharge on the left end of Fig. 15 contains two such parallel streaks close together and another displaced upwards and to the left. Clayden effect, or reversal, is present but much less marked. The galvanometer throw for Fig. 16 was two inches to right, indicating that the discharge came from a positive cloud. The throw is distinct, alone and definitely identified with the picture. This discharge, therefore, conforms to Simpson's type D_1.

The storm of August 30, 1930, as previously stated, produced an unusually large number of pictures. As will be noted in the barograph records of Fig. 9, it was similar

FIG. 15.

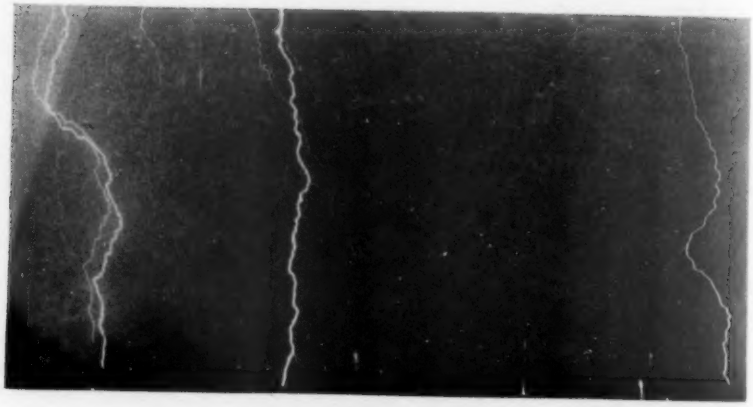
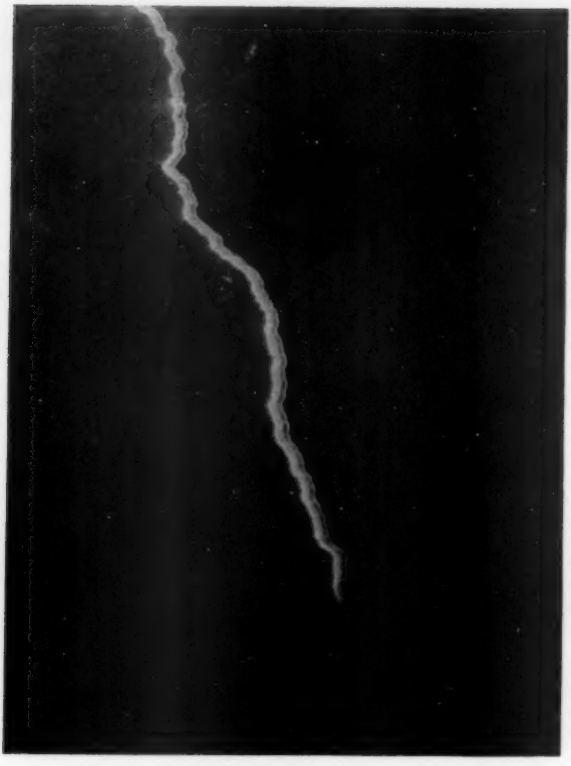


FIG. 16.



to the "double" storms described by Banerji at Bombay. Following a hot, sultry day characterized by local thunderstorms in the surrounding country, and by a slowly falling barometer, the storm was ushered in by a 30 mile wind from the west, carrying much dust, and accompanied by an unusually brilliant electrical display, at 9:40 P.M. During the first two minutes after observations were begun, with bright discharges to ground in rapid succession, five photographs of what seem to have been an exaggerated form of ball-lightning were obtained. These will be more fully described in a separate report.[1] Until the rain began at 9:52 the discharges were from a negative cloud. The bright, heavy discharges of this period are typified by Figs. 17*a* and 17*b* taken at 9:45 and 9:46½ P.M. respectively. The lightning-thunder interval on the former was 3 seconds, indicating the nearness of the storm. After the cloud came directly overhead with heavy, wind-driven rain, several pictures like Fig. 18, at 9:58 P.M., were obtained. These show no branching and are so brilliant that the quantity of electricity discharged must have been very large. This is also indicated by the fact that the galvanometer was thrown off-scale with the 4-ohm shunt. No branches are visible in any of the seven in this group but they were taken at too close range for the camera to show branching up in the cloud. The galvanometer discharges indicated a negative cloud overhead, but there were also a number of discharges of the opposite sign resulting from flashes within the cloud. At 10:19 and at 10:43½ Figs. 19*a* and 19*b* were recorded. These show distinct branching up into the negative part of the receding cloud, the branches within the cloud being somewhat obscured. Figure 19*b*, however, might have been caused by a horizontal discharge crossing one to ground. Figure 19*a* agrees exactly with Simpson's theory in producing a sharp galvanometer throw corresponding to a negative discharge from cloud to ground but unfortunately whatever field change resulted from the discharge in Fig. 19*b* was masked by another within the cloud which produced a throw in the opposite direction.

By 10:45 the second phase of this storm began, the center

[1] *Physics*, October, 1933, p. 372, vol. 4.

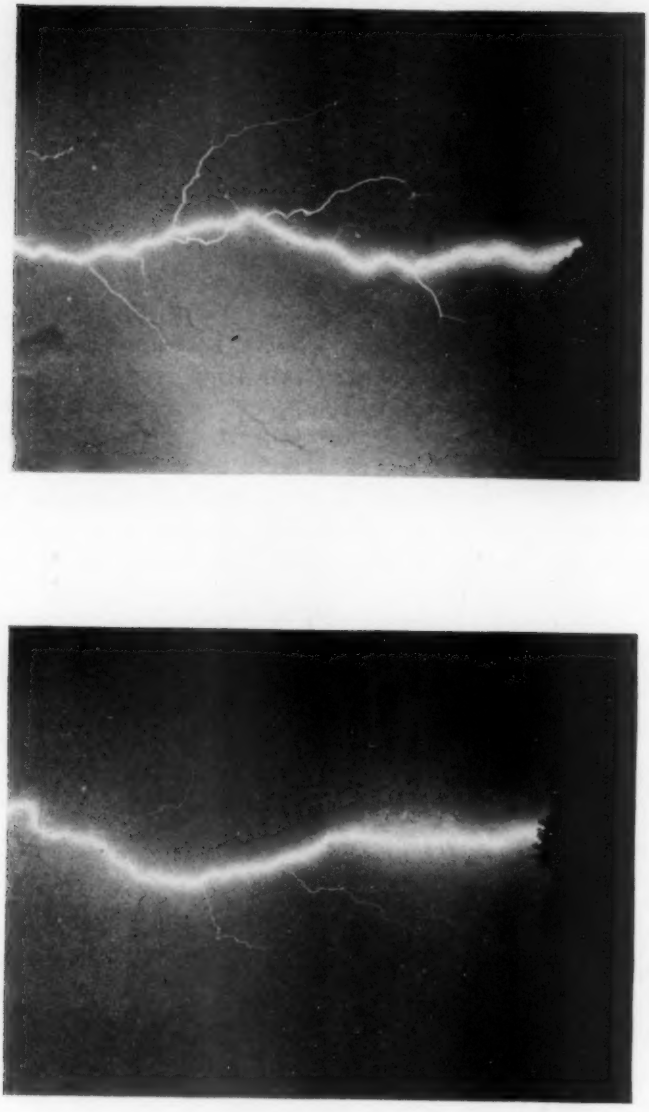
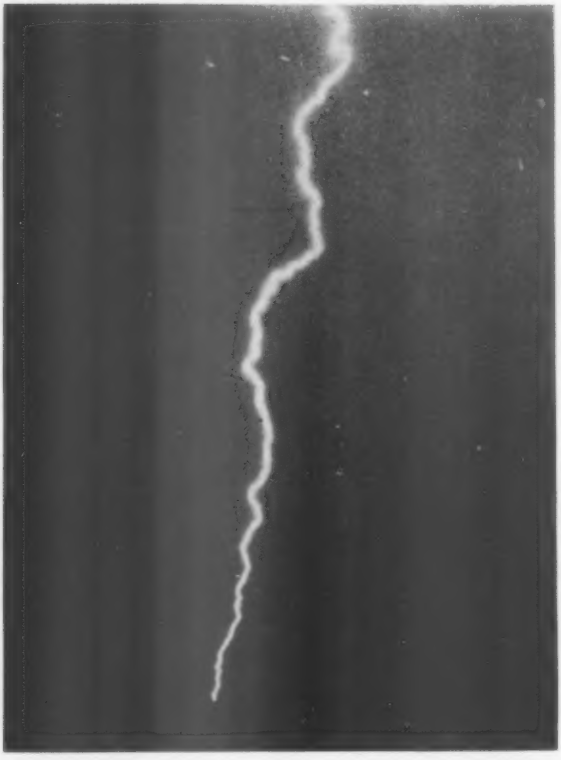


FIG. 17.

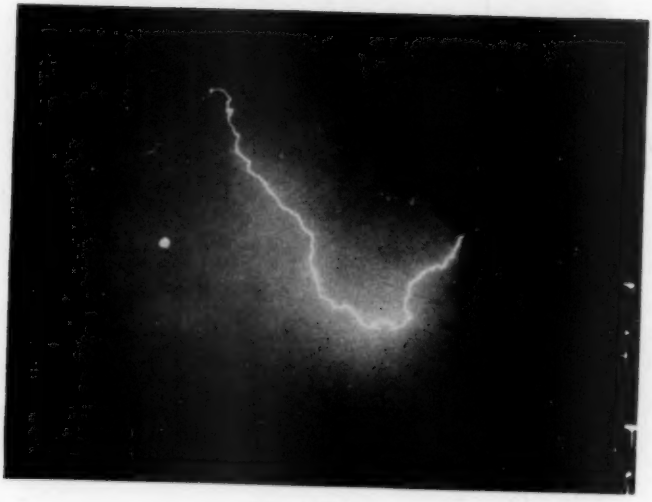
passing to the north of the observer. It was ushered in by moderate north-east winds and light rain. The electrical display was unusually brilliant. In the series, Fig. 20*a*, *b*, *c*, taken at 2 to 3 miles, are seen very large discharges of negative electricity from cloud to ground, passing through fine rain,

FIG. 18.



driven by the wind, as noted by the bending trees. The effect of the wind in carrying the lightning channel with it is particularly noticeable in Fig. 20*b*. The flash in Fig. 20*c* occurred while the galvanometer record sheet was being changed hence the direction of field change accompanying it was not noted but it certainly belongs to the same group. It is included because of the specially brilliant channel it pro-

b



a

FIG. 19.

duced. The pictures were obtained at 11:06, 11:12, and 11:16 P.M. respectively. Figure 21 is a composite made by superposing two films recorded at 11:07½ and 11:08 respectively. Their relative positions were determined from trees on the landscape which do not show very distinctly in the print. The bright channel on the right has only two very fine streamers visible near the bottom. It came from the front part of the cloud and was due to a charge of negative electricity going to ground. The discharge on the left, with its numerous fine streamers, gave a galvanometer throw only half as large as the other and opposite in direction, having come from the positive part of the cloud. This again agrees well with the Banerji cloud-type in Fig. 1*e*, as the storm was moving to the observer's right.

Mention has already been made of the laboratory experiments which show that branching may occur from a negative point to a positive grounded plane as well as from a positive point, and photographs by Peek were shown in Fig. 2 which illustrate the phenomenon. Reference to the photographs of actual lightning in Figs. 11*a*, *b*, *c*, 13, 15*a*, *b*, and 20*c*, all of which came from negative clouds, will show at once their similarity to Fig. 2*a*. It may be objected that the lightning

FIG. 20.

a

b

c

pictures are more meandering and the branches are too long and wandering. It should be recalled, however, that the laboratory discharges were in air free from convection currents and from falling rain, with a uniform electrical field, while in the cloud, and below it, the field is neither uniform nor static. In Figs. 12, 16, and the left side of 21 are exemplified the excessive and diffuse branching characteristic of a positive discharge, analogous to the artificial conditions of Fig. 2*b*.

From the above illustrations it is evident that lightning which strikes to ground may show branching from either a positive or a negative cloud, and that the positive will show more streamers and a less concentrated channel.

In Table I is given a summary of the lightning discharges photographed in twelve storms.

TABLE I.

Date.	DN.	DP.	AN.	AP.	UN.	UP.	ON.	OP.	X.
June 21, 1929	2	1					1		
July 5, 1929	2	2							
July 12, 1929	4		1			1	4		2
May 28, 1930		2							2
July 2, 1930	1		1	10					4
Aug. 15, 1930	4		2					1	4
Aug. 19, 1930	3			1					1
Aug. 30, 1930	34	4	4		1	1	3	3	2
May 17, 1931	4	2	4	3	1	2			3
May 27, 1931	6	1	9	2			2	1	1
June 21, 1931	11		5	2	2				2
Aug. 31, 1931	6	1	2	1			2	1	
Totals	77	13	28	19	4	4	12	6	21
Grand Total	185								

Legend: DN = Branching downward from negative cloud.
DP = " " " positive cloud.
AN = " across accompanied by positive field change.
AP = " " " " negative " "
UN = " upward " " positive " "
UP = " " " " negative " "
ON = No visible branching " " positive " "
OP = " " " " negative " "
X = Indeterminate.
All except AN and AP strike the earth.

The pictures listed in the above tabulation include only those for which the corresponding field changes were obtained. The accumulated totals of all lightning pictures to date give: Downward branching 207; upward branching 20; horizontal flashes 99; indeterminate 40. Included in the 20 with branches upward are several which may be composites of a vertical with a horizontal discharge. The most significant figures in Table I are those in the first two columns, DN and DP, which show that 85 per cent. of the discharges with

downward branching are accompanied by a positive field change. By the consensus of opinion of all authorities cited (p. 712), a discharge seen to strike the earth and accompanied by a positive field change must have been caused by a rush of negative electricity from the cloud to ground. The 48 discharges in columns AN and AP include only a portion of the horizontal flashes in these storms. Many of them were so hidden within the cloud that they could not be photographed, while others, especially when the cloud was directly overhead, were at too high an angle to be caught by a camera aimed at the horizon. Those classified as UN and UP are subject to more uncertainty than any of the others because of the twofold handicap of photographing through the cloud-mass and of combinations of downward with horizontal flashes already noted in Fig. 19*b*. The two groups, ON and OP, contain some very close discharges in which there may have been upward or downward branching above the angle of view of the camera, and in some cases the fine streamers may have been blurred out by heavy rain. They might easily be added to the DN and DP columns without materially affecting the results, or their interpretation. The indeterminate list is composed principally of discharges in which the direction of field change was not certainly determined.

The discharges in the first four columns of Table I have been reclassified into three divisions in accordance with the part of the storm from which they came. The first section includes the approach of the squall-cloud and the primary rain, the second the interval while the storm is overhead, and the third the period in which the storm is receding. The results are summarized in Table II.

While the points of division in this classification were somewhat arbitrary, it is interesting to note that the ratio of the

TABLE II.

	DN.	DP.	AN.	AP.
First Period	33	5	12	3
Second Period	18	5	5	5
Third Period	19	2	6	11
	70	12	23	19

number of positive, DP, to negative, DN, discharges was much smaller in the third period and was greatest in the second. Also that the proportionate number of horizontal discharges, i.e. flashes within the cloud, is greatest in the third period when the active part has passed beyond the observer, thus affording better opportunity to photograph them.

Watt has remarked (11, p. 139) that the "textbook" example of a bi-polar thunder-cloud composed of two equal point charges of opposite sign, one directly above the other, is too naive to be a frequent natural phenomenon. The same may be said regarding the heat thunderstorm of Toepler, Fig. 1*c*, which is a distinctly local disturbance. The larger and more violent storms on the Nebraska plains belong either to the "cyclonic," or to the "line-squall" type, as described by Humphreys (30, p. 348). One of the latter, which began at 9:45 P.M. on the evening of May 27, 1931, will be described briefly.

A TYPICAL THUNDERSTORM.

The meteorological conditions attending this storm are shown in Fig. 22*a*, *b*. The barometric pressure, as indicated in the record, had been slowly falling during the afternoon and early evening, accompanied by rising temperature and southwesterly winds. The cold-front of the storm arrived at 9:45 and brought mild winds, a rapid rise in the barometer, and a fifteen degree fall in temperature in twenty minutes. During this time rain was falling and the galvanometer indicated rapid changes in the electric field, Fig. 6. As previously noted, deflections upwards indicate positive changes in the potential gradient, or negative electricity escaping to earth; downward deflections result from positive charges going from the cloud downwards. It will be seen that discharges of both kinds were very frequent during the first period of the storm but that positive field changes became predominant as the storm progressed. The rapid barometric pressure fluctuations at 10:30 correspond to the high winds which reached a maximum of 43 miles per hour at 10:38 P.M. as recorded by the anemometer. This secondary storm also brought increased electrical activity and heavier rainfall. As the storm receded almost all of the discharges were indicative of negative cloud. The change of field was not caused by passage beyond

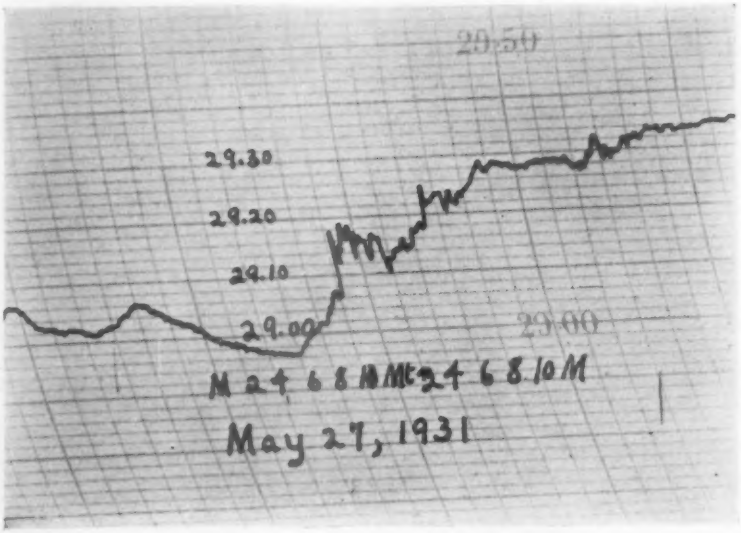
reversal distance as a discharge to ground was noted at less than 3 miles at 10:51 P.M.

The lack of similarity in distribution of electric charges between Simpson's thunderstorm and the line-squall storm of Banerji, Fig. 1*b*, *e*, consists of two items, the cold air in the back portion of the Banerji storm, lifting the whole cloud-mass higher, and the much larger distribution of negative electricity in the front of his cloud. The relatively large number of discharges carrying negative electricity to ground as reported in Tables I and II requires just such anterior negative concentration. It is well illustrated in Fig. 6, and is typical of the 40 records now on file. The anvil-shaped cloud of Fig. 21 from a typical line-squall storm, gives a longer

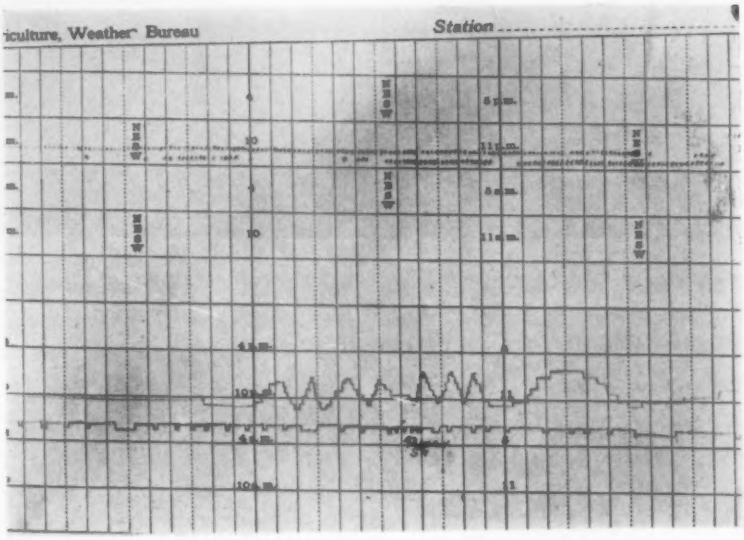
FIG. 21.

path for the negative discharge, hence requires a higher difference of potential to earth. This is precisely what would happen in Toepler's cloud, Fig. 1*d*, if the negatively charged section were driven forward in front of the positive region thus reducing the electrostatic capacity of the two sections, with a corresponding increase in potential. The probability of such action has been discussed by Toepler (8, p. 770), and by Simon (17, p. 521). The negatively charged, overhanging front in

FIG. 22.



a



b

FIG. 23.

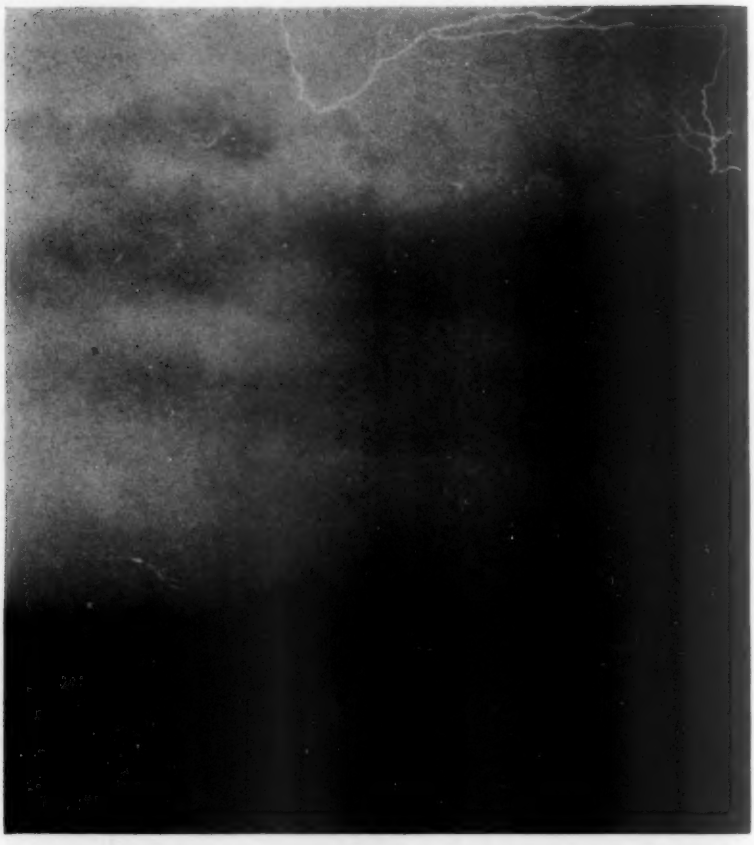


Fig. 1*d* should also be colder, and therefore denser, than the air below and so have a tendency to drop downward to produce the frontal charge of Fig. 1*e*.

The smaller number of negative field changes (positive discharges to ground or equivalent) than positive changes recorded by Wilson (13, p. 85), with totals of 279 and 432, or a ratio of 1 : 1.56, has previously been referred to. A slightly higher ratio, 1 : 1.80, obtained in the present investigation, was reported in 1930 (26). The accumulated totals to date are 2,624 to 4,504, a ratio of 1 : 1.71. In view of the differ-

ences in equipment used and in climatic conditions at Cambridge and at Lincoln, this agreement is better than might have been expected. The totals in both cases, also those given by Schonland (14, 15), include discharges within the cloud as well as those to ground. Were it possible to segregate discharges to ground of either sign from inter- and intra-cloud flashes, and those upward to the conducting layer, the ratio would be much higher as shown in Table I. Flashes like those in Fig. 23, which closely resemble those of Figs. 14 and 21 except in direction, are constantly augmenting the number of negative field changes. By carrying positive electricity to other parts of the cloud they reduce the quantity available for cloud-to-ground discharges which is in accord with the data given in Table I.

The galvanometer drifts due to charges given to the metallic deck by falling rain have a direct bearing on the process by which thunderstorm potentials are produced. Their direction for storms which passed directly overhead was such as to indicate a preponderance of positively charged rain from the active center of the storm. This was also true of our first experiments in which attention was focussed on the average charge on individual drops. It is in accord with Simpson's original measurements at Simla and with the more recent work of Banerji (6, p. 331). Watt's conclusion (11, p. 135–137) that the Simpson "breaking-drop" process is the primary factor in the production of charged drops and in the elevation of negative charges in the active area of the storm seems to be substantiated by available experimental data. The Elster and Geitel influence-machine action serves as an auxiliary factor which, as Watt points out, will increase the field, whatever its sign, while the photo-electric action of a lightning flash in causing ionization is of minor consequence.

In conclusion, it is evident that the observations and photographic evidence presented above agree in most essential points with a cloud of the Banerji type as contrasted with Wilson's bipolar form. The approach of such a storm is accompanied by heavy discharges to ground of negative electricity, characterized by bright channels with few streamers. In the second stage, with the active part overhead, some widely-branching positive discharges will occur, with negative

discharges to the sides and rear. As the storm center recedes, a lesser number of negative discharges to ground will result and comparatively few of the positive type. Lateral flashes away from the upper part of the positive section will be noted throughout the storm but will be more frequently caught by a camera when the storm center is passing to one side or after it has passed over the observer.

ACKNOWLEDGMENTS.

This research was made possible through the assistance of a number of coöperating agencies to all of whom we are greatly indebted. Grants in aid were obtained from the Bache Fund of the National Academy of Sciences and from the Hodgkins Fund of the Smithsonian Institution of Washington. The raingauge and one microbarograph were loaned by the U. S. Weather Bureau through the kindness of Dr. W. J. Humphreys; the electrometer by the University of Iowa and the ionium collector by the Carnegie Laboratory for Atmospheric Electricity and Terrestrial Magnetism in Washington. In the early stages of the investigation valuable advice and encouragement were received from Dr. G. W. Stewart and Dr. J. M. Eldredge of the University of Iowa. Professor T. A. Blair of the U. S. Weather Bureau at Lincoln coöperated in granting use of the station records and through repeated conferences on the meteorological aspects of the problem. The investigation was under the general supervision of Dr. H. H. Marvin of the University of Nebraska whose interest and counsel were important factors in bringing the work to a successful conclusion.

SUMMARY.

1. The usefulness of a battery of microbarographs for determining the path, length and rate of pressure change in a thunderstorm has been demonstrated.

2. Barographic records indicate that many of the storms observed are of the "double" type studied at Bombay by Banerji, and that two or more thunderstorms can follow each other in file.

3. The laboratory experiments of Allibone and of Peek which show branching from a negative point to a positive grounded plane have been corroborated by 77 photographs of

lightning flashes which show downward branching in discharges from a negative cloud to ground. Therefore Simpson's contention that the polarity of a cloud can be determined by the direction of branching of discharges from it is no longer tenable.

4. Evidence has been produced to show that a flash from a seat of positive charge results in many more finely branching streamers than one from a negative cloud.

5. Engineering reports that power-line outages are almost always caused by discharges of negative charges to ground are supported.

6. Accumulated totals of 7,128 field changes caused by lightning discharges give a ratio of 1 negative field change to 1.71 positive field changes, in substantial agreement with Wilson's ratio of 1 : 1.56. The larger number of field changes of positive sign is accounted for by the larger area of negative cloud in a horizontal cross section than of positive cloud.

7. The meteorological and electrical data of these experiments are shown to be in general agreement with a storm of the type described by Banerji with a concentration of negative charge in the front portion.

LINCOLN, NEBRASKA,
June 1, 1933.

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THE USE OF A VACUUM TUBE AS A PLATE-FEED IMPEDANCE.

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In designing circuits associated with a screen-grid type of vacuum tube it is necessary always to satisfy the conditions imposed by the plate-circuit characteristics. These characteristics, although indicating an impedance of the order of thousands of ohms for the steady component of the plate-current, show the impedance effective for *changes* in current to be ten times as high or even higher. In circuits for use at high frequencies it is customary to feed the plate-current through a network the impedance of which is low for direct current but which is of the same order of magnitude as the higher value of tube impedance at the frequencies for which the circuit is designed. Thus by utilizing the frequency characteristic of the load circuit it is possible to obtain, for the steady plate-current, the low impedance required in order to avoid excessive drop in plate-battery potential, and at the same time, for the signal components, an impedance sufficiently high to avoid excessive loss within the tube. Although this utilization of the frequency characteristic of the load circuit is relatively easy at radio frequencies it becomes difficult in the audio range and is impossible in the case of a direct current amplifier.

At very low frequencies, then, it is necessary to find for the plate coupling of a screen-grid tube some impedance which will be reasonably low with respect to the total current flowing in the plate circuit but which shall be of the same magnitude as the tube impedance for any incremental changes in that current. Inasmuch as this is a characteristic of the tube itself what could be more logical than to use a similar tube for this coupling?

The use of a vacuum tube as the plate coupling impedance

of an amplifier has been suggested a number of times. Mr. H. S. Reed,[1] of Bell Laboratories, has used a three element tube as the plate feed in a multi-stage direct current amplifier in such a way that the voltage drop across it would be substantially independent of normal variations in the potential of the plate-battery. Mr. John Mills,[2] also of Bell Laboratories, has proposed the use of a tube in voltage saturation, where the plate-current is independent of the plate-potential, as the equivalent of an infinite impedance. These applications were worked out prior to the advent of the screen-grid types of tube. The characteristics of these tubes, however, are such that they require, to a greater extent than do the triodes, an impedance of the type discussed. Moreover, these same characteristics make the tubes well suited to meet the requirements involved.[3] Quantitative measurements on a single stage of amplification using two screen-grid tubes of commercially available type, one as the amplifier and the other as the plate coupling impedance, have indicated performance characteristics which should prove of considerable practical value. In particular it has been found possible to build a single-stage direct current amplifier having a voltage gain of over 2,500 and a stability considerably greater than that of the equivalent multi-stage amplifier using the more conventional type of circuit.

THEORY.

To obtain an idea of the phenomena involved in a circuit arranged as suggested above let us draw a family of plate-current plate-voltage curves for a series of grid-voltages as parameter. The family shown in Fig. 1, is for an RCA-77 pentode having the screen-grid maintained at 22 volts. The performance which could be expected of this tube, using a pure resistance as the plate feed, is shown by drawing a straight line through the point of maximum plate-voltage and zero plate-current and through the operating point, or point

[1] Patent No. 1,403,566. Application filed July 11, 1919.

[2] Patent No. 1,548,952. Application filed Nov. 4, 1921.

[3] Since the completion of the experimental work here reported there has appeared, in *Electronics* for July, 1933, a note by Mr. E. R. Meissner describing an amplifier arranged in this way.

of zero signal input, *P*. The slope of this line is equal to the reciprocal of the resistance, the value in the example chosen being 1.6 megohms. As it indicates the voltage drop across the resistance for any given plate-current this line, by its intersections with the curves of the plate-current family, shows the distribution of the total plate-battery voltage between the tube and the resistance for the several values of grid-voltage. For a change in grid-voltage of 0.1 volt these curves show that the drop across the resistance changes by 21 volts.

To obtain a similar "load curve" for the case where a tube is used as the plate-feed impedance it is necessary simply to replot that curve of the family which corresponds to the fixed grid-voltage to be maintained on the coupling tube. The abscissa used will be the difference between the maximum plate voltage, or the voltage maintained across the two tubes in series, and the original variable plate-voltage. Although the tube presents the same impedance to the total plate-current at the operating point as does the resistance previously considered it is at once evident that the change in current for a given change in voltage corresponds to that obtained with a much higher resistance. Also the change in voltage across the tube for a given change in grid-voltage, is several times greater than that across the resistance, being 72 volts for a signal of 0.1 volt. In fact, to accomplish the same result with a resistance feed would require a resistance of 10 megohms (indicated by the reciprocal of the slope of the load curve) and a plate battery of 640 volts (indicated by its computed intercept on the plate-voltage axis).

In spite of the simplicity of the circuit and the limited number of elements required there are several variables at our disposal. These are: first, tubes; and second, the potentials of the several electrodes. The selection of a suitable tube was restricted at the start to that group having 6.3 volt heaters as these are most convenient for operation from storage batteries, the use of which appeared wise from the standpoint of stability and of freedom from interference, especially during a preliminary investigation. Of the tubes in this group the 77-type was shown by a brief examination to have the greatest amplification under the conditions of the

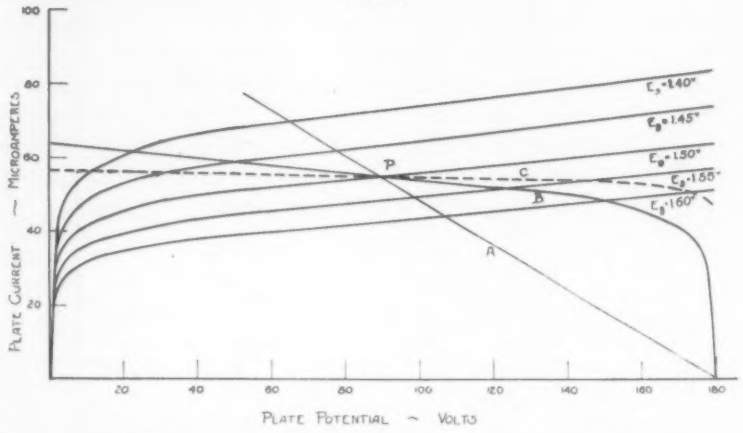
first adjustments. The data to be reported below were, therefore, taken with a pair of these tubes.

Turning our attention next to the terminal potentials on the coupling tube we see at once that the grid-bias may be obtained by introducing a suitable resistance between the plate of the amplifier tube and the cathode of the coupling tube and by bringing the grid of the latter to the negative end of this resistance. The circuit of Mr. H. S. Reed, to which reference has already been made, contains a similar resistance. Prof. C. E. Lansil of M.I.T. has pointed out that, unlike the grid-drop resistance of the conventional amplifier, such a resistance in the cathode lead of the coupling tube has a regenerative effect on the entire circuit. Inasmuch as the gain to be obtained in this way may be of considerable value this property will be examined in some detail.

The reversed tube characteristic drawn in Fig. 1, corresponds to a fixed value of grid-voltage; a similar characteristic, for values of grid-voltage depending on plate-current, may be obtained as follows. In Fig. 2 the data of Fig. 1 have been replotted to show plate-current as a function of grid-voltage, the parameter being plate-voltage. Points for the reversed tube characteristic already drawn are given by the intercepts on this family of a vertical line through the value of fixed grid-voltage. Through the desired operating point and through the zero point let us draw a straight line. This shows the value of grid-voltage resulting from the drop due to the plate-current in a resistance the value of which is given by the reciprocal of the slope of the line. Intercepts of this straight line and the curves of the plate-current family show the values of plate-current which must flow, when this voltage is used for the grid-bias, for each of the values of plate-potential, and hence furnish the data for the desire load curve. The points thus obtained are plotted on Fig. 1 as a dotted line. In this case the change in output voltage for an input of 0.1 volt is 110 volts.

It is evident that the limiting curve which can be drawn on Fig. 2 would be a horizontal line through the operating point. This would correspond to an infinite resistance and would require an infinite potential in series with the grid. By going to these limits the effect on the load curve would be

FIG. 1.



Load curves on plate characteristics of screen-grid vacuum tube.

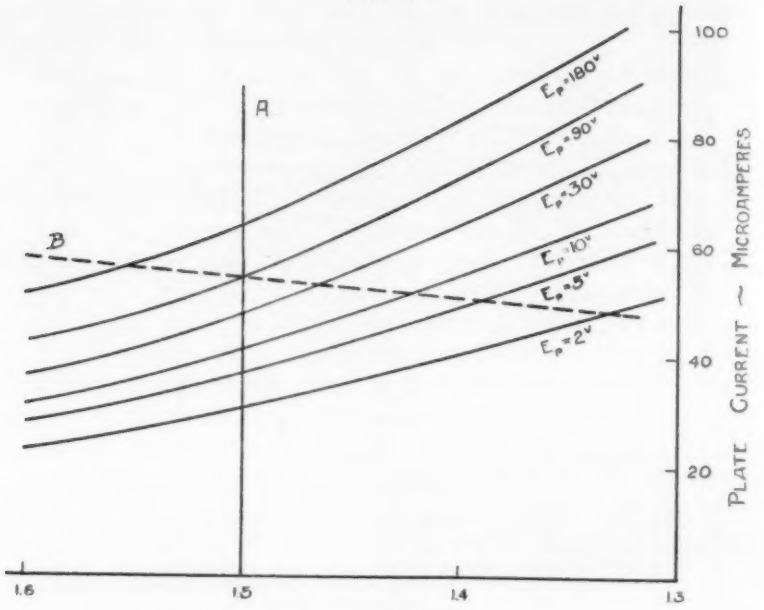
Tube: RCA-77 pentode.
Screen-potential: 22 volts.

(*A*) Load curve for resistance of 1.6 megohms as coupling impedance.
(*B*) Load curve for similar tube as coupling impedance, with fixed grid-bias of 1.5 volts and screen-potential of 22 volts.
(*C*) Load curve for similar tube as coupling impedance, with grid-bias from drop due to plate-current in resistance of 27,000 ohms in cathode lead and screen-potential of 22 volts.

to make it, in turn, a horizontal line through the operating point. This consideration of the limiting case indicates the impossibility of realizing a negative resistance by this method and assures us that the grid-bias resistance in the cathode lead may be used to increase the gain of the amplifier without danger of making the circuit unstable.

By definition the amplification constant of a vacuum tube is determined by two pairs of values of plate- and grid-potential, each giving the same plate current. A horizontal line through the plate-current curves therefore passes through such pairs of points. From this it follows that the voltage gain corresponding to this limiting case is equal to the amplification constant of the amplifier tube. When a fixed bias is used on the coupling tube the gain is equal to one-half this constant. In practice, then, it is possible to realize a gain greater than one-half the amplification constant, whereas with the pure resistance coupling originally considered the gain was considerably less than one-half the amplification constant.

FIG. 2.



Grid-bias curves on plate characteristics of screen-grid vacuum tube.

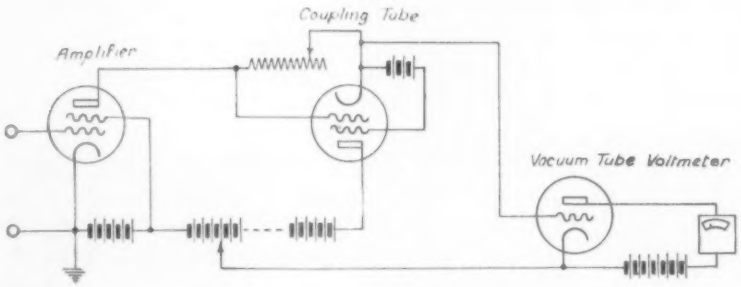
Tube: RCA-77 pentode.
Screen-potential: 22 volts.
(*A*) Fixed bias of 1.5 volts.
(*B*) Biased by drop due to plate-current in 27,000 ohm resistance in cathode lead.

PERFORMANCE.

Although the curves of Fig. 1 show the behavior of the tube-coupled amplifier in terms commonly used in vacuum tube circuit design problems and permit a computation of the relation between grid-voltage and plate-voltage, a more convenient and accurate determination of this characteristic may be made by direct measurement. For this a vacuum tube voltmeter was used. The arrangement of the circuit for this measurement is shown in Fig. 3. An RCA-89 tube was connected as a triode and calibrated for the voltage difference between grid and cathode as indicated by the plate-current through a low resistance milliammeter from a fixed plate-battery. The grid was connected to the cathode of the coupling tube and the cathode was connected to that

point on the plate-battery which, for any given condition of the circuit, brought the grid-voltage of the voltmeter tube within the range of its calibration. The voltage across the coupling tube and plate-battery was then equal to the voltage of the portion of the plate-battery required less the voltage between the grid and cathode of the voltmeter tube as given by the calibration. It may be noted here that the grid of any output tube should not be connected to the negative end

FIG. 3.



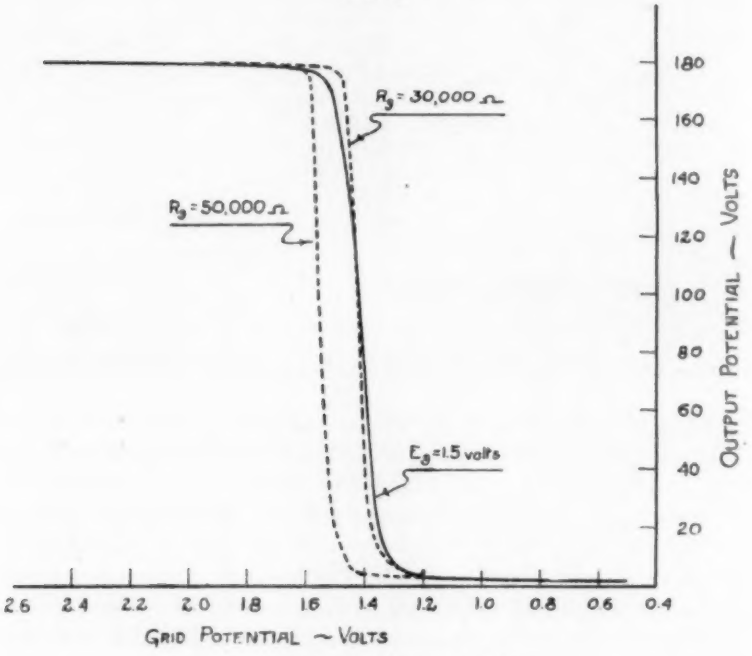
Tube-coupled amplifier with vacuum tube voltmeter for measuring amplification characteristics.

of the grid-voltage-drop resistance as any grid-current taken by the output tube, flowing as it does through both coupling tube and resistance, may cause the circuit to be unstable.

The curves of Fig. 4 show the relation between the voltage across both coupling tube and plate-battery, as measured by the method just described, and the voltage impressed on the grid of the amplifier tube. For these curves the screens of the amplifier and coupling tubes were each maintained at approximately 22 volts above their respective cathodes; the amplifier screen by means of a portion of the plate-battery and the coupling tube screen by a separate battery connected directly to its cathode. These curves give a good general idea of the operating characteristic of a tube-coupled amplifier using screen-grid pentodes. The scale required to show the entire curve, however, is such that an accurate estimate of the slope of the curve—or gain of the amplifier—cannot be made. In the laboratory study of this circuit, therefore, a direct measure of the gain was made by inserting in series with the variable grid-bias a resistance of one ohm through which a

current of one milliampere could be passed, thereby making it possible to increase or decrease the potential of the grid of the amplifier by one millivolt. In this way it was found, when using a fixed grid-bias of 1.5 volts on the coupling tube, that the gain was approximately constant at 1,250 over the range of output potential between 50 and 170 volts. Using

FIG. 4.



Characteristics of tube-coupled amplifier.

Tubes: RCA-77 pentodes.
Screen-potential: 22 volts.
Total plate-potential: 180 volts.

a grid-bias obtained from the drop due to the plate-current through a resistance in the cathode lead the gain was found to be approximately 2,250 over the range of output potentials between 50 and 140 volts. These measurements also showed that the gain of the amplifier is not greatly affected by moderate changes in the magnitude of the grid-bias resistance. The curves of Fig. 4, however, show clearly the effect of this

resistance in fixing the operating point of the circuit. In the design of a circuit for general use, therefore, it is possible to adjust the circuit to any desired value of potential across the output by adjusting this resistance.

It is interesting to note that the curve taken with a fixed grid-bias is more symmetrical than those for which the grid-bias is the drop in potential across a resistance carrying the plate-current. Although this current changes but little over the entire operating range of the circuit the effect is sufficient to alter the shape of the characteristic appreciably. For low values of negative grid-bias the current is limited almost entirely by the resistance of the coupling tube. As the bias is increased the resistance of the amplifier tube, and hence the potential drop across it, likewise increase. The decrease in plate-current, however, due to its effect on the grid-bias, causes the resistance of the coupling tube to increase at the same time, hence the knee of the curve is less abrupt at this end than when the resistance of the coupling tube is held constant by a fixed bias. For higher values of amplifier grid-bias, where the drop in potential is almost wholly across the amplifier tube, the effect of the bias resistance is to make the knee of the curve more abrupt than when a fixed bias is used.

The shape of the characteristic curve for this circuit at once suggests that it may have possibilities as a rectifier. Such is indeed the case. By adjusting the grid-bias to the value corresponding to the upper knee of the curve and applying a potential of 0.2 volt in series with the grid, at a frequency of 1,000 cycles per second, the potential on the grid on the vacuum tube voltmeter was reduced 50 volts. The circuit was also used as a detector for radio signals by connecting a tuned circuit in series with the grid of the amplifier tube and coupling to a short antenna. It was observed that, unless the grid-bias was accurately set to bring the zero-signal point onto the knee of the curve, no signals were heard in telephone receivers connected into the plate circuit of the vacuum tube voltmeter.

In the use of an amplifier such as this, stability is an important consideration. Tests were accordingly made to determine the effect upon the output potential—the potential

across the coupling tube and plate-battery—of changes in the potential of the various batteries used. As was to be expected there are marked differences between a circuit using a fixed grid-bias and one using a bias resistor. For example: with a fixed grid-bias on the coupling tube the change in output potential is almost exactly one-half the magnitude of any change in potential of the plate battery. This is, of course, a natural consequence of the approximately equal division of the battery potential between two tubes essentially similar. When the bias resistor is used, however, the change in output potential is only about one-tenth the magnitude of any change in potential of the plate-battery. In this case the resistance is functioning as in the circuit described by Reed.[4] Again, with a fixed bias, changes in screen-potential on the amplifier or on the coupling tube produce equal effects on the output potential, a change of one volt on the screen-grid causing a change of about 55 volts in the output. An increase in screen-potential on the amplifier causes the output potential to fall whereas an increase in screen-potential on the coupling tube causes it to rise. When a bias resistor is used there is little change in the effect of the screen-potential of the amplifier tube; the change in output for a given change in screen-potential on the coupling tube, however, is reduced to approximately one-half that occurring with a fixed bias. These quantities, which are intended to indicate orders of magnitude, were obtained with a fixed bias of 1.5 volts or with a bias resistor of 50,000 ohms.

Although the primary purpose in building an amplifier in the manner described above is to obtain a circuit for amplifying steady, or slowly varying, potentials it is important to know the relation between frequency and gain. It is clear from the current and voltage values involved that the effective resistance between the point at which the output potential is available—the cathode of the coupling tube—and ground is of the order of several megohms and consequently that the capacity to ground of any circuit elements connected to that point will have a direct shunting effect on the output. Unfortunately it is necessary to connect the sources of both

[4] *Loc. cit.*

grid- and screen-bias to the cathode of the coupling tube. The capacitance of the cathode itself to the heater also constitutes a serious shunt across the output. On a circuit using screen-potentials of 22 volts and a bias resistor of 40,000 ohms measurements have shown that at a frequency of 250 cycles per second the output is reduced to about one-half the zero frequency value. The resistance of the plate circuit of the coupling tube may, of course, be reduced in a number of ways, although in general such reduction will be accompanied by a reduction in the gain of the circuit. For example, by increasing the screen-potentials on both amplifier and coupling tubes to 65 volts and reducing the bias resistance to about 1,200 ohms, thereby retaining the condition of approximately equal division of plate-potential between the two tubes, the gain at direct current is reduced from 2,500 to 175. Now, however, the circuit has constant gain to well above 2,500 cycles per second and has dropped only 1.3 decibles at 10 kilocycles per second. In fact, at some intermediate point, such as at a screen-potential of 45 volts and a bias resistance of 2,400 ohms, the circuit will have higher gain at high frequencies than with an adjustment which gives high gain at low frequencies. In other words, an adjustment which may be the best for direct current or for very low frequencies may well be the worst for frequencies in the upper audio range.

APPLICATION.

Although it is true that the high impedance of the circuit is a disadvantage when working with the higher audio frequencies it introduces very little if any complication with direct currents or at low audio frequencies. In order to work into circuits of low impedance it is only necessary to provide an output stage similar in arrangement to the vacuum tube voltmeter already described in connection with the gain measurements. The connections for this output coupling tube are shown in Fig. 5. Provided the impedance of the load is not great enough to cause injurious degeneration it may be connected into the cathode lead and current brought to the positive terminal through a suitable resistance from a point on the plate-battery of lower potential than that to

which the cathode is connected. By adjusting this current to equal the normal space-current of the tube the current through the load may be reduced to zero for zero input-voltage, i.e., for the normal bias conditions on the voltage amplifier stage. In practice this neutralizing resistance may be adjusted to give zero current to the output when a fixed battery, having a potential equal to the normal operating bias of the output tube, is connected directly between its control-grid and cathode. By reconnecting the voltage amplifier and adjusting the grid-bias resistance of the coupling tube to again bring the output to zero it is evident that the voltage amplifier has been brought to the proper operating balance. It has been found that, allowing a sufficient time for the tubes to become thoroughly warmed up, the output current will remain at zero for long times without further adjustment. As previously pointed out readjustments of this grid-bias resistance may be made with but little effect on the gain of the amplifier. In general any necessary readjustments involve such small changes in the value of the resistance that it is well to provide a fine control in the form of a second rheostat having about one per cent. of the total resistance required.

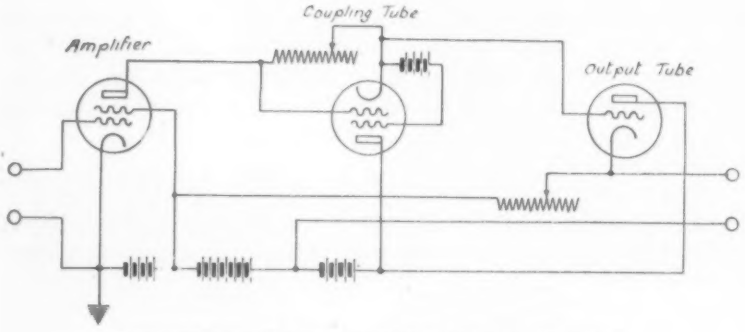
An 89-type pentode, connected as a triode by bringing the No. 3 grid to the cathode and the No. 2 grid to the plate, has been found to be a suitable tube for connecting to low impedance loads. With the cathode connected to the 90-volt point on a plate-battery having a total potential of 180 volts and with a grid-bias of 6 volts the mutual conductance of this stage was approximately 1,800 micromhos. Preceded by a voltage amplification of 2,500 this results in an overall mutual conductance for the three tube circuit shown in Fig. 5 of 4.5 mhos.

The circuit arranged as outlined above has been found to work well into an oscillograph of the moving string, or moving coil, type. Because of the large currents which may flow while the circuit is being brought into proper adjustment it is well to provide a shunt for the oscillograph element. A meter may also be included in the output circuit to aid in making adjustments. It should, however, be removed, or short-circuited, before using the oscillograph in order to avoid

the introduction of emf's due to the mechanical energy stored in the moving system.

The tube coupled amplifier, without the output circuit, has been found suitable for use directly on a cathode-ray oscillograph of the electro-static control type, the impedance of which is sufficiently high to cause a negligible increase in

FIG. 5.



Tube-coupled amplifier with output stage for low impedance load.

Amplifier tube: RCA-77 pentode.
Coupling tube: RCA-77 pentode.
Output tube: RCA-89 pentode connected as triode.
Grid-bias resistance: 30,000 ohms.
Plate-potential: 180 volts.
Screen-potentials: 22 volts.
Amplifier grid-bias: 1.5 volts.
Measured over-all mutual conductance: 4.5 mhos.

the shunt across the coupling tube. Using an oscillograph having a sensitivity of 0.2 mm. per volt, deflections of sufficient magnitude for most purposes were obtained on voltage waves having peak value of only 0.02 volt.

A circuit having the properties described is admirably suited to work involving photoelectric cells, the gain being adequate to control currents of sufficient magnitude to operate either meters or relays on very small changes in light intensity. The advantage of being able to use a direct-current amplifier for this purpose, thus eliminating any form of light chopper, is obvious.

The circuit has been tested in connection with the electromotive-forces associated with heart muscle action; the three tube circuit of Fig. 5 proved quite adequate for the operation of the counting relay used in the cardio-tachometer.

Tests have been made on a multi-stage tube-coupled amplifier. Although a two-stage circuit could be adjusted to give a gain of approximately 600,000, it exhibited the instability common to all multi-stage direct-current amplifiers. To realize the advantages of the tube-coupled amplifier in a multi-stage circuit it is evident that some form of compensation for potential changes will be required.

As in all vacuum-tube circuits the difficulties increase as an effort is made to increase the sensitivity. For moderate gains, of the order of 2,000 to one, however, the tube-coupled amplifier has been found to have advantages, both in simplicity of construction and in performance, over other types of direct current amplifiers previously used.

RELATED NODAL LINES ON SQUARE MEMBRANES.—PART I.

BY

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The differential equation of vibration of a rectangular membrane is

$$\frac{\partial^2 w}{\partial t^2} = c^2 \left\{ \frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right\}.^1 \tag{1}$$

If the rectangle is bounded by the coordinate axes and the lines $x = a$, $x = b$, a particular solution of (1) takes the form

$$w = \sin \frac{m\pi x}{a} \sin \frac{n\pi y}{b} \cos pt, \tag{2}$$

in which m and n are whole numbers while p is determined from the equation

$$p^2 = c^2\pi^2 \left\{ \frac{m^2}{a^2} + \frac{n^2}{b^2} \right\}. \tag{3}$$

For a square membrane, (2) and (3) reduce to

$$w = \sin \frac{m\pi x}{a} \sin \frac{n\pi y}{a} \cos pt \tag{4}$$

and

$$p^2 = \frac{c^2\pi^2}{a^2} \left\{ m^2 + n^2 \right\}. \tag{5}$$

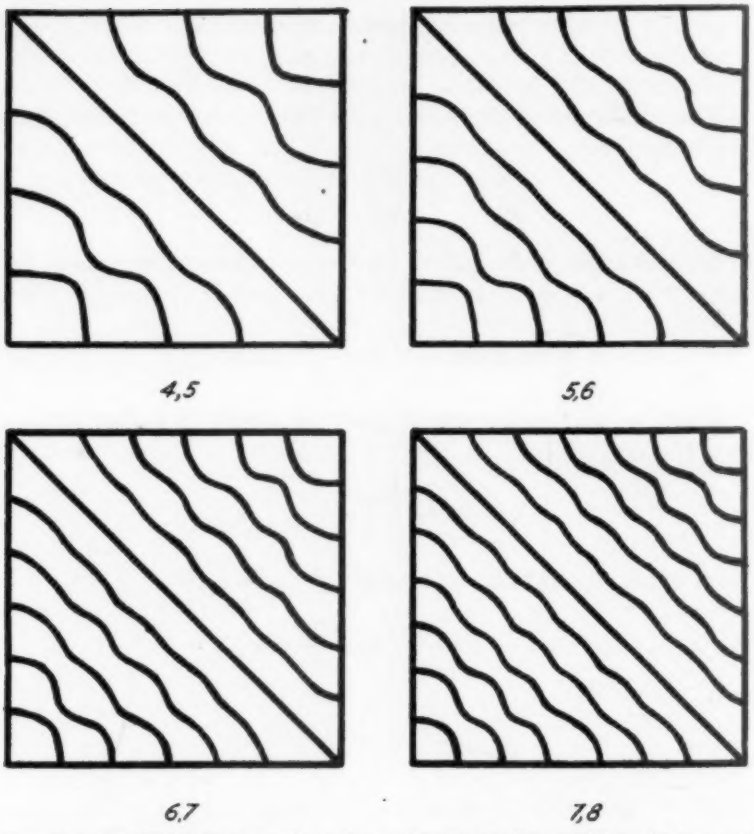
From (5) which determines the frequency of the vibration, it follows that any value of $m^2 + n^2 = a$ constant, will give the same note in the membrane. The different values of m and n which satisfy the equation $m^2 + n^2 = K$ may be found from the theory of numbers. The simplest case occurs when m and n are interchanged; since it is obvious that $m^2 + n^2$

[1] Rayleigh, "Theory of Sound," Vol. I, Chap. IX et seq.

$= n^2 + m^2$. With this simplification, the equation for the nodal lines of a square membrane becomes

$$w = A \sin\frac{m\pi x}{a}\sin\frac{n\pi y}{a} + B \sin\frac{n\pi x}{a}\sin\frac{m\pi y}{a} = 0. \qquad (6)$$

FIG. 1.

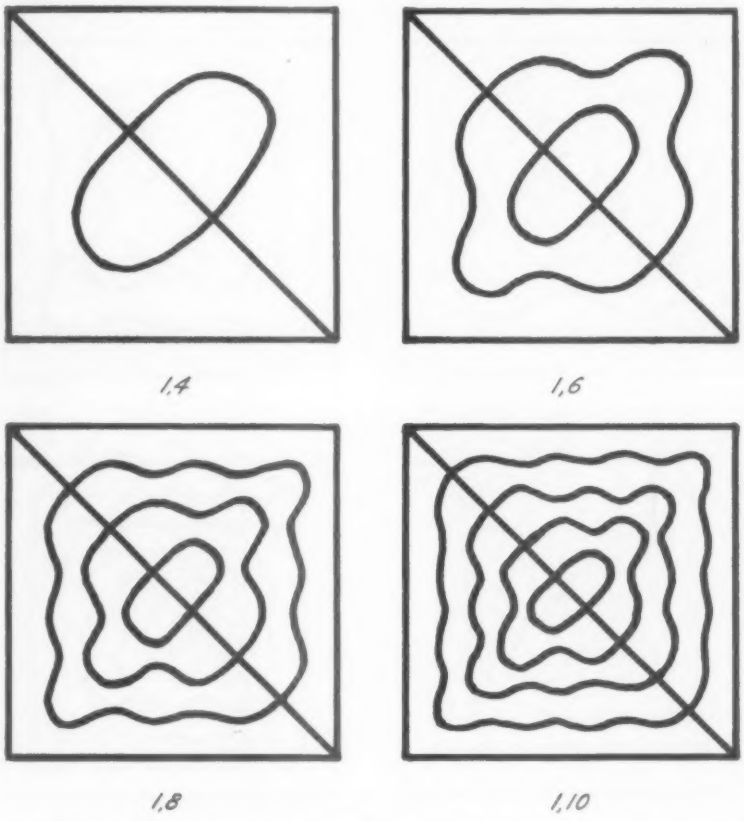


The numbers m and n increase in regular order and the corresponding nodal lines also increase in number, each figure resembling the preceding one but with two additional wavy lines.

A and B enter this equation because the two notes of the same frequency may be present in any proportion. The most symmetrical figures occur when $A = B$; all the nodal lines then having symmetry about the center and the four corners.

When equation (6) is plotted with $A = B$, and m and n increasing by regular steps, it is found that the resulting figures may be classified into certain groups. Thus for $n - m = 1$, a series of regular curves are formed symmetrical

FIG. 2.



The value of m is odd and kept equal to unity; n is even and increases by regular increments. This gives a characteristic series of nodal lines.

about one diagonal. These are shown in Fig. 1. The numbers under each diagram are the values for m and n.

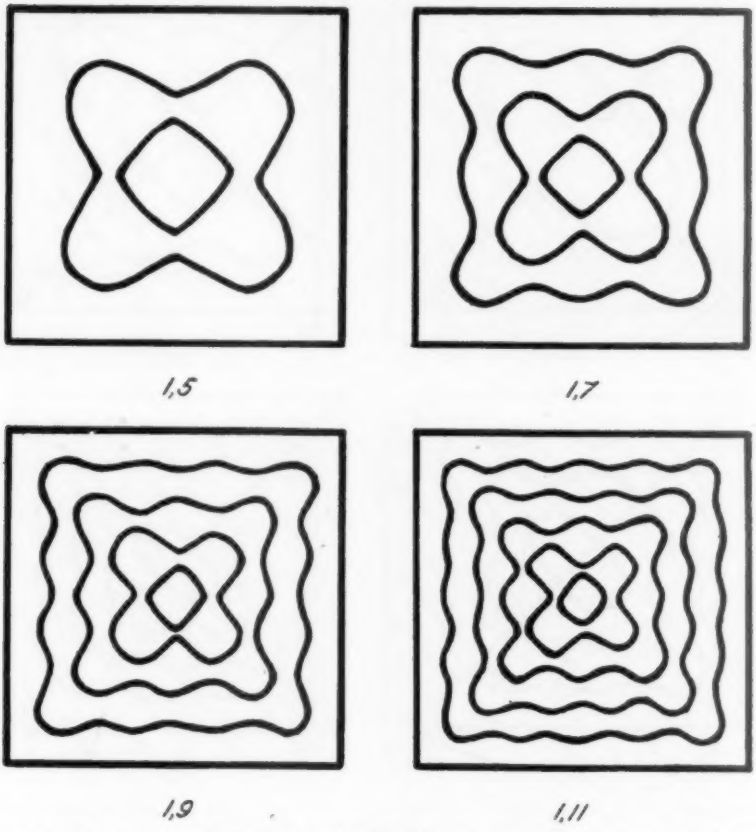
In Fig. (2), m is kept equal to one while the value in n is kept even and increased by increments of two.

In Fig. 3 m is again kept equal to one, and the value of n

is increased by increments of two, but $n + 2$ is always odd. This relation gives a characteristic group of nodal lines.

In Fig. 4 both m and n are odd to begin with and both have increments of two; this also gives a series of curves which bear a close resemblance to one another.

FIG. 3.

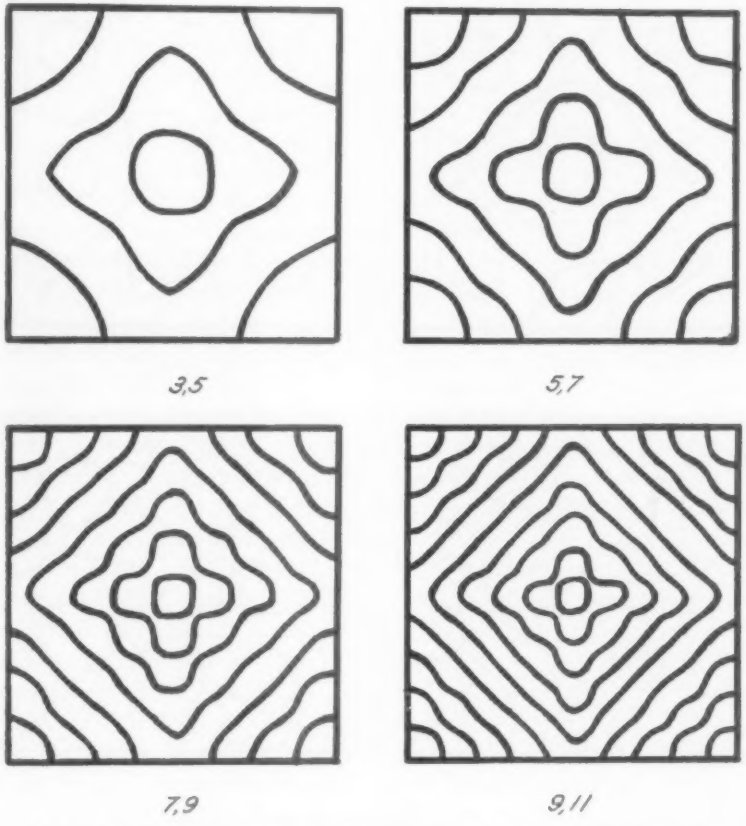


The value of m is again unity but n has odd values only. The resemblance between succeeding nodal lines is very striking.

The final figures in Fig. 5 show that for m and n both odd, the median lines parallel to the sides of the square membrane are always lines of maximum vibration; while for m odd and n even, one diagonal is a nodal line. Although they are not

shown here, even values of m and n divide the membrane into four equal squares by two medial lines through the center perpendicular to one another and parallel to the sides of the membrane.

FIG. 4.



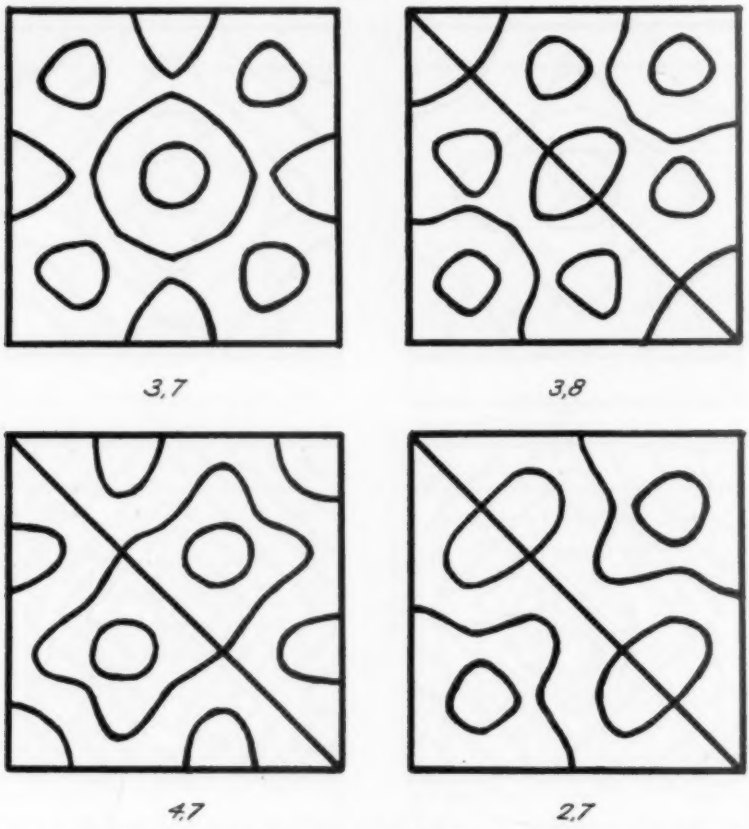
The simple figure given by (3, 5) appears at the center of all the succeeding nodal lines. For odd numbers the median lines are not nodal.

A series of figures like this is useful in plotting the higher vibrations of a membrane, since it is possible to classify any curve according to the values of m and n.

It is not easy to produce the nodal lines of a membrane experimentally because at high vibrations the sand heaps up

confusedly and does not gather exactly at the nodes; the resulting figures are much more diffuse than for the similar ones on a vibrating plate.

FIG. 5.



For the odd values (3, 7) the medial lines are not nodal; but for m odd and n even, one diagonal is always a nodal line.

RELATED NODAL LINES ON SQUARE MEMBRANES.—PART II.

BY

R. C. COLWELL, L. R. POLAN, AND E. W. NOLAND,

West Virginia University.

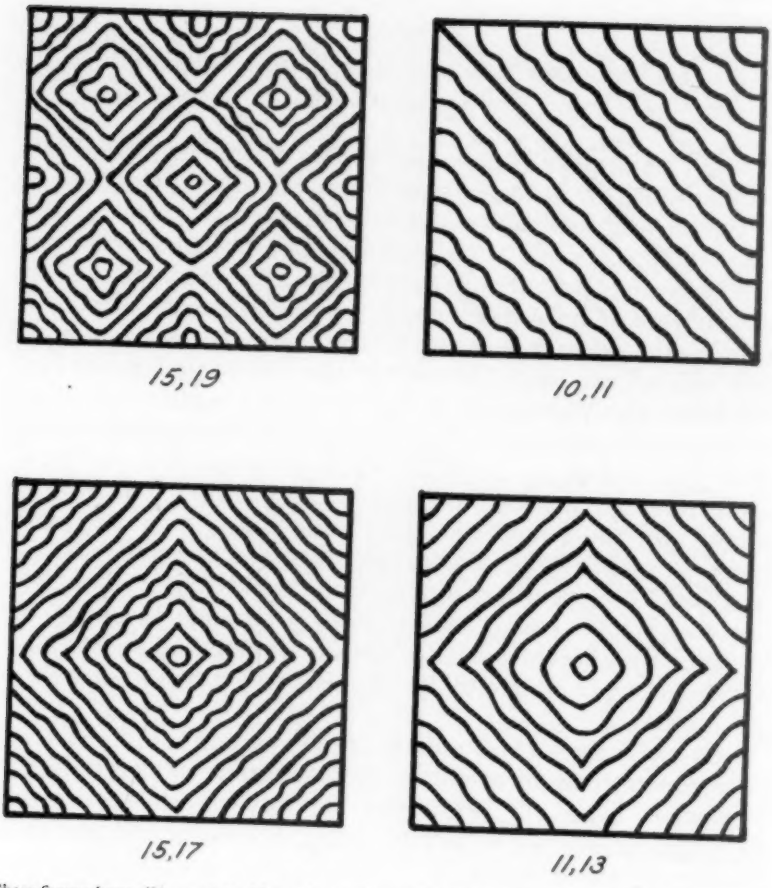
The number of nodal lines upon a vibrating membrane is determined by m and n (equation 6, part I) but the twisting of the lines depends upon the ratio of A to B. Thus if A is kept equal to B while m and n are increased, the nodal systems will be symmetrical about the center and the median lines, but the number of lines will increase for each increase in m or n. If m is changed to $m + 1$ and n kept constant, one more nodal line will appear upon the membrane. If m and n are kept constant, the number of nodal lines will remain the same but these will twist about in different directions as the ratio of A to B is changed. Heretofore, the only method of forcing a membrane into vibration was to use tuning forks or organ pipes.[1] In these methods, the tuning forks (or pipes) acted upon the middle of the diaphragm so that A was always equal to B and the resulting figures were symmetrical about the center. With a valve oscillator, it is possible to apply the vibrator to different points of the membrane and so establish some control over A and B. In this way many new figures are obtainable.

As the values of m and n are increased, the nodal lines become very complicated and the mathematical computation somewhat involved. However, we have worked out four patterns by Horner's method using a calculating machine. These are shown in Fig. 1. This method is applicable even if A differs from B. When A is equal to B a much simpler computation is possible because the general method which has been outlined for cosine functions[2] is also valid for sine

[1] Elsas, "Untersuchungen über Erzwungene Memb.," Kaiserl. Leop. Car. Akad. der. Nat, Halle, 1884, p. 1.

[2] Colwell, JOUR. FRANKLIN INST., Vol. 215, No. 2, Feb. 1933, p. 169.

FIG. 1.



These figures have all been plotted from the mathematical equations. Although they are extremely complicated, they resemble in general outline the simpler patterns of part I.

FIG. 2.

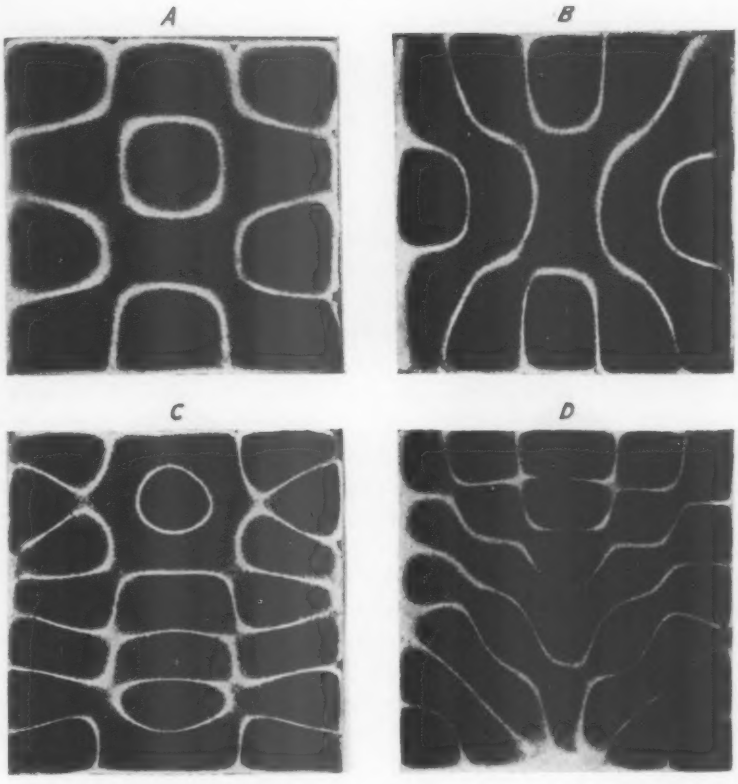
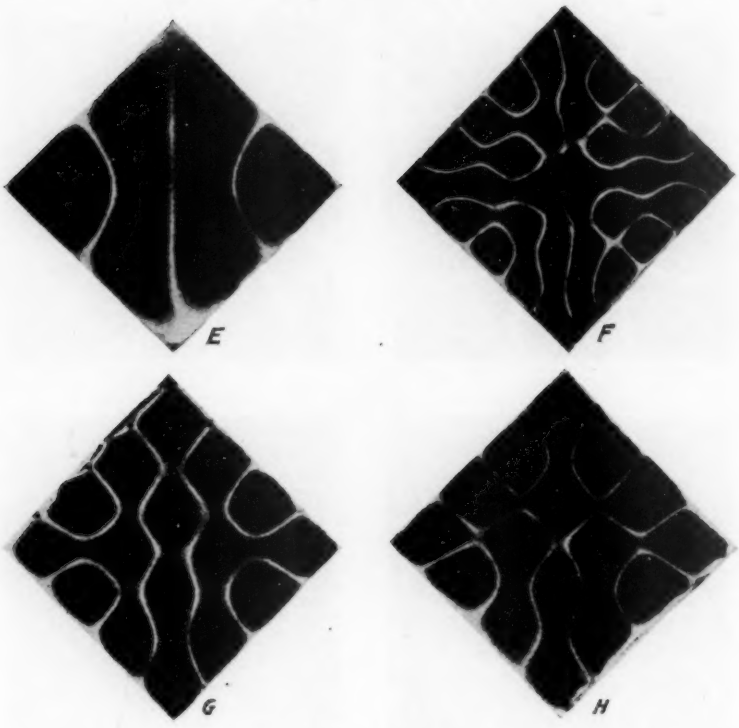


Fig. 2 continued on page 772.

FIG. 2.—*continued.*



These are photographic reproductions of the nodal lines obtained on a square membrane with the electric oscillator.

functions. For example, in finding the nodal lines from the equation

$$\sin\frac{8\pi x}{a}\sin\frac{9\pi y}{a}+\sin\frac{9\pi x}{a}\sin\frac{8\pi y}{a}=0$$

a great number of points may be obtained from the known properties of sine functions. The points which must be joined to form correct nodal lines are found from the family to which the pattern belongs. The family (8, 9) belongs to the succession (4, 5), (5, 6), (6, 7), (7, 8) shown in Fig. 1, part I. Therefore the points will be joined so as to resemble the pattern (7, 8) but with fifteen wavy lines instead of thirteen.

Not all the curves are given by a simple interchange of m and n in the equation $m^2+n^2=K$. The theory of numbers shows that other groups will also satisfy this equation. A few such pairs are (8, 1) and (7, 4); (1, 7) and (5, 5); (6, 7) and (9, 2). These numbers inserted in equation 6, part I, will give types of nodal patterns for the square membrane. The same mathematical methods are also applicable to rectangular and triangular membranes.

The nodal lines shown in Fig. 2 were produced upon a paper membrane ten inches square stretched across a wooden frame. The paper was first dipped in water, and drawn taut on the frame while still moist. In a vibrating plate, a great deal of the energy supplied is used up in heating the plate, so that the amplitude of the vibration is never very great: the air currents around the plate are not violent and the sand settles exactly at the nodes. A membrane on the other hand does not dissipate much energy in heat, so that the air around is greatly agitated. These air currents (as Faraday discovered) cause the lighter sand particles to move toward the places of greatest vibration: this action tends to make the sand figures diffuse.

Controlling Banana Ripening.—(*Food Industries*, Vol. 5, p. 341.) Most of us are inclined to take a ripe banana for granted. The fruit merchant always seems to have a goodly supply of bananas that are just the right color for eating and it is difficult to realize that under normal conditions the period of an individual banana's fitness for consumption seldom exceeds seven days. It is evident therefore that some thought and care must be applied to the harvesting of the banana in order that it will just have turned yellow by the time it reaches the retailer.

The banana is grown principally in Central America, Mexico, Colombia and the West Indies. It may take anywhere from 4 to 8 days for a shipment to reach the warehouse situated in an American seaport. As far as possible the harvesting of the stocks is timed in accordance with the required time for their transportation. However, present-day efficiency in fruit distribution makes necessary a still more rigid control of the ripening periods. Usually the ripening process is halted almost entirely by transporting to the warehouse in refrigerated compartments. Here the ripening may be completed in 3–4, 5–7 or 8–10 days as desired by regulated increases in the temperature of the rooms.

Externally, the ripening process may be indicated by the changing color of the fruit; internally by the change in sugar content. C. F. GREEVES-CARPENTER has supplemented his article with a very interesting chart showing the relations between the time after cutting, the color, the sugar and total carbohydrate contents of the banana. Under normal conditions the fruit begins to turn from green to yellow about the 11th day after the cutting of the stock. At this time the sugar content lies close to 2 per cent. From the 11th day on the sugar content increases rapidly, accompanied by rapid color changes. By the 14th day the banana is completely yellow and contains 13 per cent. sugar. Most of us have been told that bananas are best when the skin is covered with a fairly large number of brown specks. Analysis of the fruit confirms this. A maximum sugar content of 19 per cent. is attained at the 18th day. Beyond this the sugar decreases and the fruit simultaneously turns a dark brown.

Ethylene is not used extensively for ripening bananas because the natural period for the fruit is short enough.

C.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A SEDIMENTATION METHOD FOR THE DETERMINATION OF THE PARTICLE SIZE OF FINELY DIVIDED MATERIAL SUCH AS HYDRATED LIME.

Particle size measurements of finely divided materials have recently been given much consideration by manufacturers and users of such products as hydrated lime, portland cement, paint pigments, fillers, etc. Some methods of determining particle size depend upon the microscope either to make all the measurements or to calibrate another method. In order to attempt to calibrate a sedimentation apparatus proposed for use in measuring the particle size of hydrated limes, some glass spherules were prepared because their shape made microscopic measurements more reliable. These spherules were separated into fractions having a range of a few microns. In making microscopic measurements of such materials it is necessary to cover the particles with a liquid. Measurements on glass spherules, ranging in size from about 2 to 10 microns, showed that the apparent diameter changed with change in index of refraction of the mounting medium. Thus, a filar micrometer eyepiece indicated a certain spherule had a diameter of 3.8 microns when measured in a liquid having a refractive index of 1.68 but had a diameter of 4.5 microns when immersed in a liquid having a refractive index of 1.33. Because of the effect produced by the mounting medium the true particle size could not be determined with the microscope but there did exist a fair correlation between the sedimentation method and certain of the microscopic measurements.

A more complete account of this work will be published in the *Bureau of Standards Journal of Research*, probably in the January or February issue. This will include not only a comparison of the microscopic and sedimentation method for determining particle size, but also a description of the automatic recording balance and the particle size distribution of certain commercial hydrated limes.

* Communicated by the Director.

EFFECT OF JACKET WATER TEMPERATURE ON ENGINE PERFORMANCE.

Several investigators have studied the effect of high jacket temperature on the performance of liquid-cooled aircraft engines at sea level. To obtain data on the effect of changes in jacket temperature at various altitudes, preliminary tests have been made with a Curtiss D-12 engine in the altitude laboratory at the Bureau of Standards. The engine was operated at a constant speed of 2,000 r.p.m. under conditions corresponding to sea level, 10,000, and 20,000 feet altitude. Under each condition, the jacket-water outlet temperature was varied from about 30° to 95° C. The results of these tests show that friction decreases and fuel economy increases at all altitudes as the jacket-water temperature is increased. At sea level and at low altitudes the power output decreases with increasing jacket-water temperature. However, at altitudes above about 9,000 feet the power output improves as the jacket-water temperature is increased.

A further study of the effect of cylinder-wall temperature on engine performance at altitude is desirable, not only for estimating the advantages of high-temperature liquid cooling but also for evaluating the effect of cooling-air temperature on the performance of air-cooled aircraft engines.

STRUCTURAL CONDITIONS AS THEY AFFECT THE WORK OF A FIRE DEPARTMENT.

In a district made up of closely spaced buildings, the predominating type of construction has an important bearing on the possibility of conflagration and the cost and methods of fire extinguishment.

From the standpoint of fire hazard, building construction falls into the three general groups: Interior and exterior wood framing; interior wood framing with incombustible exterior bearing walls; and fire resistive construction. Buildings in the first group offer the maximum opportunity for fires to originate, and the construction is of but little value as a retardant. Exterior masonry walls afford some protection to adjacent buildings when the interior burns, but fires may

spread to the proportions of a conflagration in an area covered with such buildings. When fire resistive buildings burn, each story or fire division burns independently of the others, and this limits the volume of flame and hot gases. With floor and roof construction remaining in place, the only channel for escape of flames, hot gases, and glowing embers will be the wall openings, thus decreasing the hazard to adjacent construction.

Before the advent of modern fire resistive construction any city was subject to conflagration, particularly with the inadequate means of fire extinguishment then available. The more general use of buildings so constructed that no collapse in fires occurs even where combustible contents and trim are entirely consumed, has already increased the fire safety of the high-value districts of our larger cities.

The type of building construction also has an important bearing on the safety to life of occupants and to firemen in extinguishing fire. Irrespective of type of construction, buildings can be made reasonably safe by the provision of adequate exit ways, provided the occupants are awake, able-bodied, and not confined. The largest loss of life in burning buildings occurs in residential and institutional occupancies, and here the type of building construction is more important.

Because of radiated heat, hot air currents, and flying brands, a fire in a wood frame building is relatively the most difficult to extinguish. Exterior masonry walls afford some protection, but are very unstable after the interior has collapsed. Unless pulled inward by this collapse they tend to fall outward on account of the expansion of the inner heated surface. Properly constructed fire resistive buildings can be entered at any stage of the fire, where other conditions permit, without danger from collapses of major structural parts.

FIRE HAZARD TESTS WITH CIGARETTES.

Tests have been conducted at the Bureau to determine the fire hazard of discarded lighted cigarettes. The efficacy of certain modifications, such as slow-burning paper and the application of tips over one end was also investigated. In

making this study, the burning cigarettes were placed on representative specimens of grass and forest floor materials.

Untipped cigarettes that continue to burn after being lighted, may cause fires when discarded, although when placed on grass and forest floor materials, a draft was found necessary to produce flaming ignition. As determined at the level of the exposed material placed with its surface in an inclined position and with the air current impinging thereon at an angle of 45 degrees, the range in air velocity most favorable for ignition was from 3 to 4 miles per hour. With the surface of the materials in a horizontal position and the speed of horizontal air currents measured a few inches above the materials, the range in which the highest percentage of ignitions occurred with most of the materials was from 6 to $7\frac{1}{2}$ miles per hour. The air speed at the surface of the exposed materials would be expected to be considerably lower.

Under the conditions of the test, with the most favorable drafts and with relative humidities in the range 25 to 50 per cent., fires were caused on the average by nine out of ten lighted half-length untipped fast-burning cigarettes discarded on grass, forest litter, or duff. The percentage of cases resulting in fires increased somewhat with decrease in relative humidity.

The fire hazard of the slow-burning type of cigarette was found to be much lower than for the fast-burning type. In the former the glow will not progress appreciably after the cigarette is discarded while the latter will continue to glow until fully consumed.

The fire hazard of discarded lighted cigarettes can be decreased by applying tips of cigarette paper. In tests with half-length fast-burning cigarettes having tips one inch long of paper similar to that used on this type of cigarette, four fires occurred on the average for every ten trials. With tips of the same length made of the paper used on slow-burning cigarettes, the occurrence of fire in the exposed materials was reduced to one out of four trials.

The placing of tips on cigarettes is practical from the manufacturing standpoint, and, as made of cigarette paper, they should not be objectionable to the user.

WRITING INK FOR PERMANENT RECORDS.

As the result of many experiments, the Bureau has found a writing ink which apparently will not deteriorate paper. After inking, papers were subjected to accelerated aging by applying heat. When heated, the ordinary acid type of writing ink caused rapid embrittlement of the papers, in some cases the folding endurance being decreased 50 per cent. The type of ink believed to be satisfactory is alkaline; ammonia replaces the acid of the usual type of ink. There was practically no embrittlement of papers inked with this preparation when they were subjected to the heat test.

AMERICAN STANDARD FOR GAGE BLANKS.

On October 30 the American Standards Association officially approved as American Standard B47-1933, the commercial standard for gage blanks, CS8-33, as drafted by the American Gage Design Committee. This constitutes the first revision of the commercial standard which has been in effect since 1930, extends the range of sizes, and includes certain types of gage blanks not previously covered such as adjustable snap gages, adjustable length gages, and combination ring and snap gages.

The project constitutes an outstanding example of voluntary self government in industry, whereby standards are voluntarily drafted and adopted jointly by producers and consumers as a basis for better understanding and fairer competition in the production and purchase of the commodity in question. This is made possible without government dictation or domination, it being the function of the Bureau to act as a coördinator in the work and to record the standards finally accepted by the industry.

This standard will become effective for new production on January 1, 1934, and for clearance of existing stocks January 1, 1935.

Cranberry Jelly with the Correct Quiver.—(*Food Industries*, Vol. 5, p. 348.) Unlike many fruit juices that of the cranberry jells without difficulty; in fact many manufacturers of jelly complain that cranberry juice sets up much too rapidly. Now it is known that a substance natural to fruit juices, named pectin, is responsible for their jelling. When there is too much pectin, acid or sugar present, the gelation will be premature and the result is a jelly which will not retain the shape of its container nor at the same time exhibit any "quiver." In this condition the preparation may more aptly be termed a sauce. In order to prepare a jelly which will retain its molded shape, have "quiver" and spread well, the directions furnished by R. E. Cox may be followed.

The unsatisfactory behavior of the natural cranberry pectin is eliminated by adding an enzyme, pectinase, to the berry pulp cooled to 100° F. The pectinase completely decomposes the pectin in a few hours. The temperature then is raised to boiling to destroy the pectinase and a specially prepared grade of slow-setting pectin now is added. The juice so treated can be poured into the molds before the jelling occurs.

C.

Touch Not or Drink Deep.—(*Food Industries*, Vol. 5, p. 372.) A beverage consisting of pure juice from the fruit of the passion flower has recently become available. The passion flower, a plant indigenous to North America and transplanted to South America and New Zealand, derives its name from six pistils resembling the Biblical crown of thorns. The juice naturally contains pepsin and a very interesting feature is its ability to simulate different flavors at different degrees of dilution.

While we are on the subject, mention also might be made of a carbonated coffee drink at the present available in restricted localities. Containing coffee, sugar, flavors and carbonated water, it is meant to be served as a ready-made iced coffee.

C.

NOTES FROM THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

PRELIMINARY REPORT OF THE RESULTS OF ANGULAR DISTRIBUTION MEASUREMENTS OF THE COSMIC RADIATION IN EQUATORIAL LATITUDES.

BY

THOMAS H. JOHNSON,

Assistant Director.

A preliminary survey of the angular distribution of the cosmic radiation in equatorial latitudes has now been completed and measurements have been made in Mexico,[1, 2] geomagnetic latitude 29°, at elevations 10,000 ft., 7,500 ft., and sea level, in Panama, geomagnetic latitude 20° at sea level, and in Peru, geomagnetic latitude 0°, at elevations 14,000 ft., 11,000 ft. and sea level. As a part of the same program E. C. Stevenson has also completed measurements with similar apparatus at Swarthmore,[3] geomagnetic latitude 51° and sea level, and in Colorado,[4] geomagnetic latitude 49° and elevation 9,500 ft. All measurements were made with a train of three Geiger-Mueller counters [5] arranged in line with a circuit for recording the coincident discharges. The counting rate was thus a measure of the intensity of that part of the radiation lying within the range of directions subtended by the outside counters. The principal measurements compared the intensities in the eastern and western azimuths at identical angles from the zenith and for this purpose frequent changes of orientation were made by rotation about a vertical axis. In the Peruvian and Panamanian measurements these changes were made automatically at thirty minute intervals

[1] T. H. Johnson, *Phys. Rev.*, **43**, 834 (1933).

[2] Confirmatory measurements were also made in Mexico by L. Alvarez and A. H. Compton, *Phys. Rev.*, **43**, 835 (1933).

[3] T. H. Johnson and E. C. Stevenson, *Phys. Rev.*, **44**, 125 (1933).

[4] E. C. Stevenson, this issue.

[5] T. H. Johnson and J. C. Street, JOUR. FRANK. INST., **215**, 239 (1933).

and readings were taken photographically at fifteen minute intervals. The large amount of data, made possible by automatic operation, has reduced the probable error of the west-east differences in many cases to about five per cent. In all latitudes the eastern intensity was less than the western, and the greatest differences were found on the magnetic equator. At the elevation of ten thousand feet and zenith distance of forty-five degrees in Peru the east intensity was thirteen per cent. less than that of the west, in Mexico seven per cent. less, and in Colorado, two per cent. less. The west-east differences for the three elevations in Peru satisfactorily fit the equation

$$\Delta(\theta) = \alpha\chi(\theta)e^{-\mu h \sec\theta}. \qquad (1)$$

This has been derived using the results of the Lemaitre Vallarta theory for associating minimum energy with angle and assuming a corpuscular component uniformly distributed throughout the range of Lemaitre and Vallarta's energy parameter, x_0, from 0.35 to 0.75. $\Delta(\theta)$ is the west-east intensity difference at zenith distance θ expressed as a fraction of the average intensity at the same zenith distance, and $\chi(\theta)$ is the difference between the minimum energies (x_0) permitted at the same zenith distance from the east and from the west respectively as evaluated from Vallarta's curves.[6] μ is the difference between the absorption coefficients of the asymmetrical component and of the total radiation and h is the depth below the top of the atmosphere. The curves of Fig. 1 represent equation (1) with $\mu = 0.1$ per meter of water, $\alpha = 2.3$ and values of h corresponding to the three elevations at which measurements were made in Peru. The experimental values are also included and the agreement is satisfactorily within the probable errors, although the values of the constants may be slightly modified by a least-squares solution. The fact that μ is positive accords with the findings of Compton,[7] and of Bowen, Millikan and Neher [8] that the radiation which accounts for the latitude-intensity changes is softer than the total radiation.

[6] M. S. Vallarta, *Phys. Rev.*, **44**, 1 (1933).

[7] A. H. Compton, *Phys. Rev.*, **43**, 387 (1933).

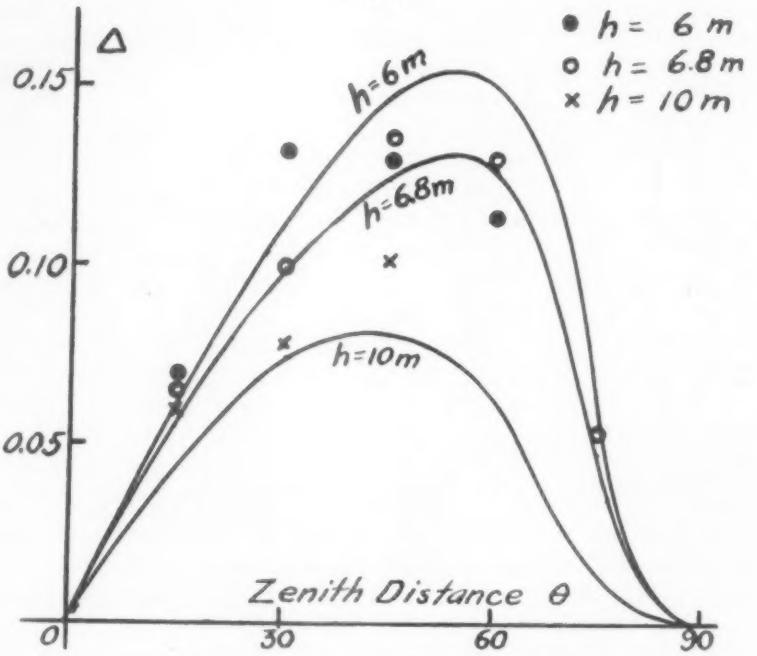
[8] I. S. Bowen, R. A. Millikan, and H. V. Neher, *Phys. Rev.*, **44**, 246 (1933).

In correlating the magnitude of the asymmetry with the latitude-intensity variations the following equation has been used.

$$D(\lambda, \theta) = \alpha\psi(\lambda, \theta)e^{-\mu h \sec\theta}. \qquad (2)$$

D is the fractional increase of intensity at a particular angle θ between latitudes o° and λ and ψ is the corresponding difference in minimum energies as evaluated from Vallarta's curves. The constant α in eq. (1) represents the excess of positive over negative radiation and in (2) α represents the sum of the positive and negative. If we assume that all of the radiation is positive α has the same significance in both equations, and the latitude intensity change as it would be measured with an electroscope may be calculated by integrating D over all values of θ. For the latitude of Mexico

FIG. 1.



Calculated and observed asymmetries for three elevations on the magnetic equator.

the above stated values of the constants determined from the asymmetry predict an increase of intensity over that at the equator of 6.6 per cent. at sea level and 11.5 per cent. at 14,000 ft. These are almost exactly the values found by Compton. For Panama the predicted change is about one-third of that for Mexico. Since any admixture of negative radiation would diminish the asymmetry but would add to the latitude-intensity changes this comparison is a sensitive test of the assumption that the radiation within the effected range of energy is entirely positive.

Further evidence that there is no appreciable mixture of negative radiation results from determinations in Mexico, Panama, and Peru of the dependence upon azimuth of the intensity of the radiation at a zenith distance of approximately forty-five degrees. Measurements were made in the west, southwest, south, southeast and east azimuths and at all stations a continuous increase of intensity was found from the east to the west with no indication of a second minimum in the west such as would be expected if an appreciable amount of negative radiation were also present.

If the conclusion is sustained that all of the corpuscular radiation is positive this would seem to restrict the Lemaitre theory of the radioactive origin of the corpuscular cosmic radiation and would suggest the hypothesis that this component is generated in a cosmic, or in a hitherto unknown terrestrial electric field. The cosmic radiation, therefore, may not be uniformly distributed throughout space and estimates of the fraction of the total energy in the universe based upon this assumption may be considerably in error.

The present measurements give no definite evidence concerning the character of the undeflected general radiation though it is perhaps significant that the four component analysis which Bowen, Millikan and Neher [8] have just given the intensity measurements, is nearly in accord with the angular distribution at both sea level and 14,000 ft. This agreement would tend to support the underlying assumptions of their analysis that the radiation consists principally of photons. Their recent three component analysis and the earlier analyses of Millikan and Cameron [9] are not satisfactory

[9] R. A. Millikan and G. H. Cameron, *Phys. Rev.*, **37**, 247 (1931).

from this point of view and this fact would suggest that angular distribution curves may be used in conjunction with intensity measurements in arriving at more definite solutions of the cosmic ray energy bands.

A complete report of this work is in preparation and it will contain acknowledgments to the many who have co-operated to make these studies possible. Part of the funds used have been made available from the Carnegie Corporation of New York by the Carnegie Institution of Washington and part were supplied by the Bartol Research Foundation of the Franklin Institute. Acknowledgment is also made of the generous aid of Sr. José de la Macorra.

THE DISTRIBUTION OF COSMIC-RAY NUCLEAR DISINTEGRATIONS IN TIME.

BY

C. G. MONTGOMERY AND D. D. MONTGOMERY.

In connection with the investigations of W. F. G. Swann and the authors on nuclear disintegrations produced by cosmic rays,[1] the question arose as to whether these disintegrations occurred individually and collectively at random in time. To test this, observations were taken for a thirty-five hour period with the large ionization vessel and recording system previously described. The time intervals between the occurrence of bursts of ionization larger than four million ions in nitrogen at a pressure of 100 pounds per square inch were measured, and the number of intervals between certain limits were obtained. These data were compared with the numbers to be expected by the method used by Marsden and Barratt[2] for alpha particles. If n is the number of intervals greater than t_1 and less than t_2, N the total number of intervals, and τ is the average interval, then n is given by

$$n = N(e^{-t_1/\tau} - e^{-t_2/\tau}).$$

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[1] W. F. G. Swann and C. G. Montgomery, *Phys. Rev.* (2), **44**, 52–53 (1933).

[2] Marsden and Barratt, *Proc. Phys. Soc.*, **23**, 367 (1911); **24**, 50 (1911); v. Rutherford, Chadwick and Ellis, "Radiations for Radioactive Substances," Cambridge, 1930, p. 172.

The agreement between these expected numbers and the observed ones can be seen from the accompanying table. The fit between the observed and calculated values has been

t_1.	t_2.	n.		Difference r.	Divergence $= r^2/n$ calc.
		Calculated.	Observed.		
0 sec.	50 sec.	19.38	22	+ 1.62	0.14
50	100	17.89	17	− 0.89	0.04
100	200	30.46	26	− 4.46	0.65
200	500	63.47	68	− 4.53	0.32
500	1000	50.48	47	+ 3.48	0.24
1000	2000	26.62	31	+ 4.38	0.72
2000	5000	4.69	2	− 2.69	1.54
5000	∞	0.01	0	0	
Totals		213.00	$N = 213$		$\chi^2 = 3.65$
					$r = 521.6$ sec.

measured by Pearson's criterion and the value of χ^2 obtained is given in the last column. From distribution tables of χ^2 we find [3] that the probability of a divergence greater than this is between 0.7 and 0.5. Thus the data are in good accord with the hypothesis that the nuclear disintegrations observed are randomly distributed in time.

The authors wish to express their thanks to Dr. W. F. G. Swann for his enthusiastic support.

SWARTHMORE, PA.,
October 5, 1933.

AZIMUTHAL ASYMMETRY OF THE COSMIC RADIATION IN COLORADO.

BY

E. C. STEVENSON.

An investigation of the azimuthal asymmetry of the cosmic radiation near Fulford, Colorado, geomagnetic latitude 48° N., elevation 9500 feet, shows a difference between the west and east intensities of about two per cent. for angles of

[3] T. C. Fry, "Probability and Its Engineering Uses," New York, 1928, p. 468.

30° and 40° from the vertical. The measurements were made with the same apparatus and in the same manner as at Swarthmore.[1] The results are summarized in the table, and are in accord with those found at Swarthmore.[1] Also there is agreement with Korff [2] who set an upper limit of 3 per cent. for the west–east difference with an indication of a slightly greater west intensity. The dispersion of the points on the curves of Stearns and Bennett [3] indicate that their probable errors were too great to detect such a small asymmetry as exists at these latitudes.

Angle from Vertical.	Total Time T (min.)	Total Counts C.	Counting Rate C/T.	Number of Data n.	Probable Error from Residuals R.	Probable Error from Total Counts R'.	West–East Difference Counts/min.
0°	1432	16,552	11.56	20	0.064	0.061	0
30° east	3951	30,463	7.71	25	0.031	0.026	0.17±0.045
west	4169	32,843	7.88	28	0.032	0.029	
45° east	4186	19,867	4.74	26	0.026	0.023	0.11±0.034
west	4801	23,295	4.85	25	0.022	0.022	

This investigation was made possible by the invitation of Dr. A. J. Allen to spend a few weeks at his cabin in the mountains and use the facilities of his hydro-electric plant.

SWARTHMORE, PA.,
October 23, 1933.

[1] Thomas H. Johnson and E. C. Stevenson, *Phys. Rev.*, **44**, 125 (1933).
[2] S. A. Korff, *Phys. Rev.*, **44**, 515 (1933); *Phys. Rev.*, **44**, 130 (1933).
[3] J. C. Stearns and R. D. Bennett, *Phys. Rev.*, **43**, 1039 (1933).

A Break for Talkers.—In *The Week's Science*, E. E. FREE describes a new noiseproof subway car designed by engineers of the Interborough Rapid Transit Company, New York City. The car amounts to what is really a noiseproof box. Windows are kept closed and all cracks through which noise could enter are sealed. Forced ventilation is provided by power blowers, the air ducts being acoustically treated to prevent passage of noise through them, on somewhat the same principles as the noiseproof ventilators now used for windows.

Just to what degree the noise in a subway car is reduced by correct soundproof insulation was not left to argument which undoubtedly would arise were the question to be settled by the subjective recordings of the human ear. Rather, noise meters were put on the job so that little uncertainty existed regarding the magnitudes of sound intensities registered by these novel instruments. Noise meter measurements made in ordinary subway cars with the windows open, as is necessary in summer, indicate an average noise level of about 95 decibels, which is about the noise of Niagara Falls as heard from the closest point which a visitor can reach. For subway riders to talk to each other at this noise level they must shout loud enough to be heard, in quiet country at night, for almost two miles. Independent measurements indicate the noise level inside the new cars has been reduced to 75 decibels or one-hundredth of the former value. This is about as quiet as the average Pullman car with its windows closed. Ordinary conversation often reaches this 75 decibel level. Home radio music and the noise of city streets frequently are louder.

C.

Vitamin C Content of Strawberries and Strawberry Ice Cream.—C. R. FELLERS and M. J. MACK (*Ind. Eng. Chem.*, Ind. Ed., 1933, XXV, 1051–1052) find that fresh strawberries of the "Klondike" and "Howard Supreme" varieties are an excellent source of water-soluble C, the vitamin which protects the animal from scurvy. The vitamin content of the strawberries was not impaired by freezing with or without the addition of sugar, by storage in a "freezer" at a temperature of 0° C. for periods as great as 7 months, or by incorporation in ice cream.

J. S. H.

THE FRANKLIN INSTITUTE
Philadelphia : : : Penna.

OPENING OF THE FELS PLANETARIUM

November 1, 1933, 3.30 o'clock P. M.

PROGRAMME

Quartette . . . . . *Haydn*

CURTIS QUARTETTE

Address of Welcome . . *The President of The Franklin Institute*

Ladies and Gentlemen: By authority vested in me as President of The Franklin Institute, I have the honor to welcome you today at the opening of the Planetarium of the new Franklin Institute Museum and Benjamin Franklin Memorial. This Museum has been made possible by the wisdom of the City and the generosity of eleven thousand individual citizens.

The Franklin Institute accepted the responsibility of planning and constructing this gift and we hope and feel confident that you are satisfied with the beauty of the structure which we have placed on this famous Parkway—a structure which in our opinion has the dignity worthy of that famous man whom it was built to honor.

The Franklin Institute also has the responsibility of making the Museum a vital and useful part in the educational life of the Community and on this day we dedicate ourselves to this work, which, with God's help, will be an incentive and an inspiration to the present and future youth of our great City. This responsibility, however, should not be taken by The Franklin

Institute alone, but should be shared and enjoyed by every citizen of Philadelphia.

Every person entering this Museum will pay his homage to the great practical philosopher and scientist, Benjamin Franklin, but we eleven thousand people who have worked in making it a possibility, will also give thanks that it was our privilege to have known that kindly gentleman, Cyrus Curtis, who led us and gave us the inspiration.

Today we open the first section of the Museum, the Planetarium, given by one of the valued members of The Franklin Institute and one of the distinguished citizens of Philadelphia, Samuel Fels. This Planetarium, properly exhibited, will be of incalculable value in educating not only the youth of the City but the adults. It is only one of the many parts of the Museum which will eventually be opened to your city, but it will be many months and even years before the Museum will be in its completed form; in fact it will never be completed. Such a Museum will be and should be always changing and growing.

The building in which this Museum stands we open today, a building whose grace is a joy to all who pass it, and I wish to introduce our Architect, John Windrim, whose masterly control of proportions, whose clear vision of beauty and whose accurate understanding of construction have made this building possible—John Windrim.

Presentation of the Keys of the Planetarium

The Architect, John T. Windrim, Esq.

Mr. Fels, I regard it as an honor and a privilege to present you with the key which will open this beautiful planetarium which you have made available for the public.

Donation of the Planetarium to The Franklin Institute

Samuel S. Fels, Esq.

Mr. President: Those very advances with which science and invention have broadened knowledge and

understanding have unexpectedly narrowed the habits of many people. Men and women engaged in any pursuit tend to concentrate on it and often forget that much of importance is to be found outside the narrow confines of the daily routine.

The heavens themselves helped the peoples of the past to keep out of such ruts. Our ancestors were not cooped up in cities. On each clear night they could look upon the stars and the planets without those obstructions which our modern environment puts in the way. Many of them knew the vast map of the heavenly bodies and all sorts and conditions of men shared in the nightly contemplation of the stars. They raised their eyes to the sweep of the heavens and it lifted them out of themselves.

In our time, we have to leave the city behind us to get so broad and satisfying a view of the sky at night—or one which will rouse a sense of participation in our universe. It was this that first caught my imagination, when my good friend, Dr. David Riesman, of the University of Pennsylvania, on his return from Europe told me enthusiastically how he had sat beneath the stars of a Planetarium and in a few moments had witnessed the pageant of the seasons.

The idea impressed me so much that I came to the conclusion Philadelphians should have the opportunity of such an experience, one which I hope may cause many to begin to know as much about stars as they do of traffic lights.

After all, the heavens are ours to love and to study if our cities only have the ingenuity to annex them. They have a special meaning for us in times such as these. The earth under our feet is fixed and we tend to fashion our habits of thought on it. The heavens constantly change, but there is order in their movements. We can draw confidence from them in addressing ourselves to the problems and promises of our changing world.

The Benjamin Franklin Memorial seemed to be the natural channel through which such an opportunity

might reach the people of Philadelphia; so I joined with its trustees and as result, here it is before you. If the satisfaction that has come to me in my efforts to bring it to you are equalled by the pleasure and profit that others receive from it, my object will have been accomplished.

To show Philadelphia's appreciation of that wonderful citizen, Benjamin Franklin, this beautiful structure which surrounds us has been erected and the exhibits are being put into place. The Planetarium is the first department to be ready and we meet here today to open it officially for the education and pleasure of Philadelphians and the glory of Benjamin Franklin.

It gives me, Mr. President,much satisfaction to hand to you, as representative of The Franklin Institute, these keys and this Planetarium as the first completed evidence of the great work of the Benjamin Franklin Memorial and of The Franklin Institute.

Acceptance..... *The President of The Franklin Institute*

Mr. Fels: In accepting these keys in the name of The Franklin Institute, I pledge the whole membership to the responsibility of making this Planetarium a living force in the life of Philadelphia. It was you, sir, who, alone, conceived the idea of bringing this great mechanical teacher to Philadelphia, and you not only conceived the idea but brought it to fullfillment by ordering the apparatus and presenting it to the Institute. In the name of The Franklin Institute and of the citizens of Philadelphia I thank you for the gift and accept the trust symbolized by these keys.

Presentation in absentia of Dr. Walther Bauersfeld, Carl Zeiss, Inc., Jena, Germany, for the Cresson Medal
The Secretary of The Franklin Insitute

Mr. President: The desire for a physical device to represent accurately the heavenly bodies and the effort to produce such an instrument, are centuries old. Many such instruments, varying in beauty and interest, have been made, but none of them is fairly comparable

with the amazing instrument which we are to enjoy today in the multiplicity of the phenomena which it displays, in the accuracy with which it displays them, or in the magnitude and spectacular quality of the effect which it produces.

The production of this beautiful mechanism is the outgrowth of the desire of the Director of the Deutsches Museum of Munich for a device which should simulate the heavens accurately and in their beauty. Dr. Walther Bauersfeld of Carl Zeiss Inc., Jena, solved the problem—a most difficult problem—and produced what is known the world over as The Zeiss Planetarium, which you see represented here before you.

We have wished to have Dr. Bauersfeld with us today, in order that we might pay deserved honor to him for the vast knowledge and the surpassing ingenuity which he has shown in this product of his inventive ability. To our great disappointment, he has been imperatively detained in Germany—I am sure to his disappointment as well.

In his absence, we have asked Dr. Bauersfeld's associate and my friend, Herr Franz Fieseler, der Bevollmächtigter der Firma Carl Zeiss to be present on this occasion and to represent Dr. Bauersfeld. Herr Fieseler has just arrived in New York from Germany on a journey which he has undertaken, in large part, if not wholly, in order that his great organization might be fittingly represented on this happy occasion and has done us a highly appreciated service and honor.

Mr. President, I have the honor to present, in absentia, Dr. Walther Bauersfeld of Jena, Germany, as the recipient of the Elliott Cresson Medal, upon the unanimous recommendation of the Committee on Science and the Arts of The Franklin Institute, "in consideration of the invention of a mechanical and optical device to reproduce on the inside of a white hemispherical screen the naked eye stars and planets as seen from any part of the earth at any time and to represent their motions, so speeded that changes taking many centuries can be shown in a few minutes—the

whole constituting an apparatus which has proven of exceptional value in explaining astronomy to the layman as well as for the solution of technical problems."

Received by Franz Fieseler, Esq., on behalf of Dr. Walther Bauersfeld

Mr. President—Ladies and Gentlemen: Owing to unforeseen circumstances, Professor Dr. Bauersfeld, the creator of the Zeiss Planetarium, has found it impossible to leave Jena at this time for the necessary period so that he might be present this afternoon, as he wished. Dr. Bauersfeld regrets very much indeed that he could not visit Philadelphia on this festive occasion and receive personally the Elliott Cresson Gold Medal, conferred on him. He asked me to assure you that he fully appreciates the high honor bestowed on him by you and is most thankful for this distinction.

I have been designated, therefore, to represent him and the firm of Carl Zeiss at the opening of the Fels Planetarium and to receive, on behalf of Dr. Bauersfeld, the Elliott Cresson Gold Medal. While realizing that I am only a poor substitute, I confess that I am glad to be here and to have the great pleasure of meeting once more that public-spirited, generous and amiable donor of this instrument you see before you—Samuel Fels—and other dear friends whom I need not call by name.

In consigning to you the instruments supplied by my firm for the Planetarium and for the Observatory, I want to express the wish that both the Planetarium and Observatory may largely contribute to the development and furtherance of astronomical knowledge among the population of Philadelphia, of Pennsylvania and her neighboring States.

Nocturne . . . . . *Borodin*

CURTIS QUARTETTE

Address: "The Importance of the Planetarium to Science, to Education, and to Recreation" . . *Dr. Heber D. Curtis, Director, Astronomical Observatory, University of Michigan*

The astronomer sees, and with a great deal of satisfaction, a wide-spread, genuine, and rapidly growing interest in popular astronomical knowledge.

This interest is now so general as to be well-nigh universal. A Japanese gardener recently discovered a comet, and has received a medal therefore. I myself have endeavored, in the wilds of Northern Sumatra, to explain some of the facts of the solar system to a primitive Gayo tribesman. "Mau tahu," "I want to know," he said over and over. We are like him in that we "want to know"—an insatiable curiosity, rather a desire or impulse, to find out all about our surroundings.

As evidences of this trend, astronomical articles are not only frequent in our daily press, but all evidence goes to show that such articles are widely read and commented upon. All colleges and many of our better high schools furnish adequate instruction in this fascinating field.

Not all the results of this wide-spread hunger for understanding can be approved by the astronomer; there are followers of every field of thought who distort and twist the findings of the scientist, or even misuse his results. The astronomer shudders, if he reads them at all, at the astrological sections in our daily press, the articles on "You and Your Stars" which tell you what you ought to be and how different your fate if you were born one week later. These features seem to be inserted on the not always happy principle of giving to all the public all things that only small sections may wish.

For no modern astronomer believes in astrology, or that Saturn's place in the heavens at the hour of one's birth determines a life and character. Since the opening of the Adler Planetarium in Chicago it is said that on all the streets leading to it the number has doubled of astrological parlors, numerologists, fortune tellers, and palm readers.

The astronomer can but smile and shrug his shoulders at such strange deductions from his science, but realizes that a little of the strange and wierd nearly always

may be found in the train of any field of knowledge. The influences of astronomy on human thought is becoming so wide-spread that perhaps the man in the street feels himself justified in demanding that the universe shall tell him, or arrange for him, a wise marriage, or a successful journey. We demand some notice from the cosmos of our own insignificance.

As I seek for the fundamental reason why the man in the street, the merchant in his office, the professor in his study, all alike seem eager for astronomical knowledge, I come to a conclusion which may appear new to some of you. Why are the majority of people apparently more interested in astronomy than in history, or medicine, or biology?

My own personal conclusion, or explanation of this strange fact, is that astronomy, for some evident reasons, seems to have a closer contact with what I shall call the great "unanswerable questions" that at one time or another in one's life, come to the mind of lettered and unlettered alike, demanding an answer that may be forever beyond us.

Why are we men here?

What is the meaning and purpose of mankind, just two billion microbes on a speck of dust we call the earth, swinging around a star called the sun, whose whole system is as a grain of sand in the greater universe outside?

How did things start?

Are we and our universe just an accident, an aimless happening, resulting from haphazard physical laws, or is there instead a higher guiding purpose, some nonmaterial spiritual control?

Though these questions may never be answered fully, man has been trying to answer them for ages, and will never cease to attempt to find answers. Different men have found different answers. We must always look with tolerance on answers that seem to us vague and incorrect, and praise rather the universal effort to find these answers.

Kipling has phrased tolerance well as regards creeds, and his words fit these greater questions as well—

> "My brother kneeleth, saith Kabir,
> To brass and stone in heathenwise,
> But in my brother's voice I hear
> My own unanswered agonies.
> His God is as his Fates assign;
> His prayer is all the world's—and mine."

My analysis, then, leads me to think that the fundamental reason for the attraction of astronomy comes from the fact that astronomy, more than any other science, gives us a glimpse of the infinite. I shall show later that this may be said literally, rather than figuratively, of our most modern astronomy.

Now we must admit, at the start, that infinity is an exceedingly large word. Only three classes of people—philosophers, religious believers, and astronomers—really talk at all seriously about infinity. Astronomy, it would seem, is the only actual science which has the right to talk about infinity.

Now I can make no claim to rank with the first of the classes I have named—the philosophers—though I really rather envy the philosophers. They seem to be such a comfortable and on the whole happy lot, needing no mighty telescopes or expensive laboratories to carry on their work, but letting the rest of us collect the data for them. They need no laboratories other than those in their heads that Nature gave them. Of course, even Nature sometimes makes mistakes. But because the apparatus is so conveniently at hand and so inexpensive, all of us are philosophers of greater or less degree.

I do, however, claim to belong to the second and third classes I mentioned as dabbling in infinity—the religious believers, and the astronomers. Here we meet the interesting and significant fact that the astronomer of today is soberly and seriously considering, even sometimes postulating so mighty a thing as an infinite universe. As a matter of fact, there have arisen during the past ten years about half a dozen different astro-

nomical theories of an infinite universe. While some have been supplanted, the important point, for my argument, is that there has been even *one* such theory, a point to which I shall return directly. One sort is like our world of everyday life with its three-dimensional perception of space and time. There have been, in addition, several sorts of expanding, contracting, or oscillating infinite universe theories transcendental in that, following the theory of relativity, the world is assumed to have four instead of three dimensions. These theories must be regarded as still in a formative stage; it is very doubtful that our universe is actually expanding, and the scientist and layman alike will do well to adopt a conservative and waiting policy for a time.

Now we today are not vitally interested in the extremely intricate mathematical details of these infinite universe theories. The important and highly significant fact which stands out from what I have just said is that astronomy is adopting today the concept of an infinite universe in sober mathematical earnest, and many in the audience doubtless feel that mathematics is always sober.

All of you have some faint idea of the enormous numerical aspects of modern astronomy. We give the world a picture of our sun as just a respectable middle-aged star among the few billion brother stars that form our Milky Way. We now speak of millions of other Milky Ways, of trillions of suns, of distances so vast that when we express them in miles we must put down 22 figures in a row. These vast concepts are not, however, the really important fact.

The most significant and valuable contribution of astronomy to modern thought, in my opinion, is just this same sober postulation of infinity mentioned earlier. This new concept is even now having a most important and marked influence on current religious and philosophical thought.

Let me repeat to impress on you the significance of what I have just said.

If a scientist soberly thinks of an infinite universe, why may not the religious believers or the philosopher assume the same right and as scientifically to ponder on other sorts of infinity—eternity, infinite power, infinite goodness and truth? In such a postulation they will be as scientific as the astronomer, and derive their support and pattern from him and his infinite universe.

Let me pass now from such mighty imaginings to the purpose of the beautiful equipment we dedicate today. I often wish I had a small-size planetarium next to my classroom. Almost instantly, and better than through hours of verbal explanation, I could bring home to students the mechanism of our motion in space, the configuration of the stars, the changing heavens through the centuries and millennia as our earth nods on its axis.

830,000 people have visited the Chicago planetarium during the World's Fair only.

To me the most important and significant feature of a planetarium is the universality of its appeal. All, whether trained in astronomy and other science, or illiterate, seem to grasp its teachings with a rapidity and a thoroughness which is remarkable, perhaps because unexpected.

Millions, literally, here and in Germany, have gone forth from such demonstrations with a clearer understanding of the majesty and wonder of the heavens in which we move and have our being. They are better citizens of the universe because of this added knowledge. Perhaps, too, they have received some help in trying to answer for themselves, some of the "unanswerable questions." Such an education is of tremendous value to the soul of mankind. No one can know the universe, even in part, without an exaltation of spirit, and a feeling of pride in being a unit of so glorious a structure.

I am purposely refraining from details as to the minutiæ of the celestial phenomena that are taught so clearly through the planetarium; such facts would be

out of place here, even if time permitted me to summarize them in detail. Let us look only at the larger benefits, leaving the details to the work of the planetarium staff.

All through the years to come, this great Fels Planetarium will be a source of both instruction and inspiration to the millions who live in this region. It will be an education of value, accurate in detail, secured, as in all worthwhile instruction, through the eye as well as the ear.

But much as I value this education in celestial things to be given by the Fels Planetarium, I place a far higher value on its inspirational teachings. This in the belief that such knowledge is good for the soul of man; for never has it been more true that "we live not by bread alone."

Violin Solo . . . . . *Iso Briselli*

Demonstration of the Planetarium Instrument . *James Stokley, Associate Director for Astronomy, The Franklin Institute*

Mr. Stokley, Associate Director for Astronomy on the museum staff of The Franklin Institute, displayed the workings of the planetarium instrument and showed some of the things which could be demonstrated by its aid, to the great enjoyment and satisfaction of a large audience.

(PROCEEDINGS OF THE STATED MEETING HELD WEDNESDAY, NOVEMBER 15, 1933.)

The regular monthly meeting of the Institute was called to order at eight-fifteen P.M. by the Secretary of the Institute, who presided.

The acting Chairman introduced Mr. J. H. Jackson, a representative of the United Campaign, a welfare organization, who spoke briefly of the needs of the community and the desirability of contributing to the welfare drive.

The acting Chairman announced two proposed amendments to the By-laws which would be offered for the consideration of the members of the Institute at the monthly meeting on February 21, 1934. He explained that last April an amendment to the By-laws was adopted, by which a new type of membership in the Institute, known as "Family Membership" was established. Privileges of this type of membership were: unlimited admission for all members of the

household to the planetarium and the museum, the use of the library, and the right to attend the meetings of the Institute but without the right to vote or hold office.

The two amendments which will be presented at the February meeting and which are signed by Mr. W. Chattin Wetherill and Mr. Haseltine Smith, members of the Institute, call for the establishment of two new classes of membership, to be known as "Franklin Institute Museum Membership in The Franklin Institute" *a* and *b*.

(*a*) Family Membership: Such memberships extend unlimited admissions to the museum and the planetarium to all persons who are named as members of the household by the person paying the fee. Individual cards of admission will be sent to the persons so named. The fee is twenty dollars per year.

(*b*) Individual Memberships: Such memberships extend unlimited admission to the museum and planetarium to an individual who pays a fee of ten dollars per year.

The Chairman announced that the proposed amendment was designed to change the nature of the "Family Membership" which had been authorized in April and to establish the new type of individual membership.

The Chairman then announced that there was no other business and introduced as the lecturer of the evening Mr. H. B. Meller, head of Air Pollution Investigation of the Mellon Institute of Industrial Research, Pittsburgh, Pa., who spoke on the important subject, "Clean Air an Achievable Asset."

Mr. Meller described the researches which had been carried out in Pittsburgh and in the matter of air pollution and air purification and outlined the results which had been attained in that city. He also described the procedure which might be adopted with advantage by any city in protecting its air against pollution. Mr. Meller's talk was followed by a brisk discussion, during which many questions were asked of him.

The meeting adjourned at nine-thirty-five P.M., with a rising vote of thanks to the lecturer.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, November 8, 1933.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 8, 1933.

MR. THEOBALD F. CLARK *in the Chair.*

The following report was presented for final action:

No. 2968: Machines and Apparatus for Generating Double Helical Gears.

This report recommended the award of the Edward Longstreth Medal to Mr. William E. Sykes, of Buffalo, New York.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, November 15, 1933.)

FAMILY MEMBERSHIP.

MR. HENRY S. HARRIS, Mechanical Engineer, Philadelphia, Pa. For mailing: 4 Greenwood Place, Wyncote, Pa.

MR. W. E. HOLLAND, Philadelphia Storage Battery Company, Ontario and C Streets, Philadelphia, Pa.

MRS. ARTHUR B. HUEY, 1816 De Lancey Place, Philadelphia, Pa.

MR. CLARENCE V. ROBERTS, 6439 Cherokee Street, Germantown, Philadelphia, Pa.

MRS. AGNES K. ROGERS, 854 Buck Lane, Haverford, Pa.

RESIDENT.

MR. JACOB J. CRESKOFF, Structural Engineer. For mailing: 5220 Gainor Road, Philadelphia, Pa.

MR. CHARLES GAY, Narberth, Pa.

MR. ARTHUR A. FLEISHER, Retired, 2301 Green Street, Philadelphia, Pa.

MR. HARRY E. HODGSON, Assistant Superintendent, Philadelphia Gas Works Company, Thirty-first and Passyunk Avenue, Philadelphia, Pa.

MR. SAUNDERS LEWIS, JR., Retired, 240 South Twenty-first Street, Philadelphia, Pa.

MR. J. LIVINGSTON POULTNEY, Mechanical Engineer, Philadelphia, Pa. For mailing: Haverford, Pa.

MR. JOSEPH G. STALB, Heating and Ventilating, Reading Iron Company, Philadelphia, Pa. For mailing: 22 Partridge Avenue, Ridley Park, Pa.

NON-RESIDENT.

MR. JOHN MARSHALL, DuPont Company, Wilmington, Del.

REV. JOSEPH J. SULLIVAN, Chemist, Holy Cross College, Worcester, Mass.

CHANGES OF ADDRESS.

MR. FRITZ V. BRIESEN, 49 Wall Street, New York, N. Y.

MR. CHARLES M. BURRILL, 148 Ardmore Avenue, Haddonfield, N. J.

MR. CHARLES H. COLVIN, Egbert Hill, Morristown, N. J.

MR. G. H. CONDICT, 74 Park Lake Avenue, Orlando, Florida.

PROF. F. O. DUFOUR, Narberth Hall Apartment, 300 Essex Avenue, Narberth, Pa.

MR. HENRY C. EVANS, Spring Lane, Roxborough, Pa.

DR. DUNCAN G. FOSTER, 302 North Chester Road, Swarthmore, Pa.

MR. J. H. GRANBERY, 433 West Twenty-first Street, New York, N. Y.

MR. G. R. HALL, 21 Cassilis Avenue, Bronxville, N. Y.

MR. WALTER G. HENSEL, 479 Delaware Avenue, Buffalo, N. Y.

DR. HOWARD B. HOLROYD, 2530 Maiden Lane, Altadena, Calif.

MR. WILLIAM M. KERR, Lincoln Liberty Building, Room 822, Broad and Chestnut Streets, Philadelphia, Pa.

MR. JAMES LYMAN, 1221 Forest Avenue, Evanston, Ill.
MR. IGOR V. MARKOFF, 131 West Tulpehocken Street, Germantown, Philadelphia, Pa.
MR. FRANKLIN P. MCCONNELL, 100 South Fourth Street, Darby, Pa.
MR. WAYNE B. NOTTINGHAM, 10 Preble Garden Road, Belmont, Mass.
MR. L. A. OSBORNE, RCA Building, 30 Rockefeller Plaza, New York, N. Y.
MR. L. K. SILLCOX, 519 Washington Street, Watertown, N. Y.

LIBRARY NOTES.

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BOOK REVIEWS.

THE WORLD OF FOSSILS, by Carroll Lane Fenton, 182 pages, illustrations, 13 × 19.5 cms. New York, London, D. Appleton-Century Company, Inc., 1933. Price $2.00.

Here is a book which should be read at leisure, if that is possible under the NRA. I was forced to read it in snatches, in the subway, hanging from a strap in a reeling trolley and occasionally in the arm chair. Some books have to be read under the right conditions to taste the proper flavor. And so with The World of Fossils, read it by all means and as your eye travels through the last chapter, make sure that you are in an easy chair facing a fire that is signalling with a wisp of flame, wig-wagging as it were to homo sapiens. Turn the last page and subside into the silence of deep reflection—an imperative rite of reading.

The book opens with the hunting of big game, and such game, the repulsive Dinichthys welcoming little fishes into its evil jaws, the cacops on his way up stream and up land, the dimetrodon, the "tiger of the Permian Delta," paleoscinci, cynognathi, pl.enacodi, baluchitheria, titanotheres, mastodons and finally strangest of all homo sapiens. The sweep through the past that comes from a mere recitation of the names of those strange creatures of strange and far distant time compels a thoughtful person to reflect. The passage of time appears as a puny phrase. The sweep of ages helps one's perspective. The cosmic cycle (whatever that means) seems to be nearer the true facts as disinterred and pieced together by geologists, paleontologists and their assciates, the bone men.

There is one very fetching passage at the end of Chapter II. After a hard climb the Fentons scaled their thousand feet of "mud cracks and ripples and vanished shores" dropped hammers and looked aloft at still higher peaks. A shimmer of white light on a shaggy coat, the glint of sharp light on the shin of a black horn and they spied a mountain goat watching their intrusion. At their feet were the fossils of algæ, so old and primitive that the inexpert would think them rocks. Above their heads was the most specialized and (Carroll Fenton suggests) the most modern of alpine animals, the mountain goat, in between man or to be exact a man and a woman.

When I stood on the pavement that flags the driveway to Mr. Skinner's residence in Holyoke I had that same strange sensation. In the paving stone were the great prints of the dinosaur, residents of the ancient Holyoke (?) and on top of those prints stood the balloon tired cars that had brought guests to dinner. Intricate powerful, smooth machines making no imprint, patiently waiting the master's touch to breathe into motion. Dinosaur to automobile, paving stone to

car. I fancied, that while men dined indoors, the cars talked to the foot prints. And what do you think they said?

Read Carroll Fenton's book on fossils and part of that conversation will be revealed. Some of it you know already, but Schuchert's maps are always interesting. The simple illustrations clearly drawn help the story. A few misprints and one mistake in grammar need bother no one. Last evening I saw the feathers on a mosquito's wing under the eye of a microscope, which has the ultimate capacity of magnification to 1700 diameters. I did not have any idea that there were such feathers in the world but there are. Some day they may be fossilized under a fossil "scope" and some future fossilologist will write:

"Man at last had won the chance to dream, and his dreams turned to things of beauty."

H. W. ELKINTON.

INDUSTRIAL CHEMISTRY, AN ELEMENTARY TREATISE FOR THE STUDENT AND GENERAL READER, by Emil Raymond Riegel, Ph.D., Professor of Industrial Chemistry, University of Buffalo, 784 pages, tables, illustrations, 15.5 × 23.5 cms. New York, The Chemical Catalog Company, Inc., 1933. Price $6.00.

This volume is composed of fifty chapters and within the scope of this half-century will be found a description of every industrial chemical process of any consequence. Assuredly the author has fulfilled completely the primary and secondary purposes of his book. First, he presents in a single volume a faithful picture of the numerous commercial activities which make up industrial chemistry; second, the book is to be suitable as a class room text in the industrial chemistry course such as is usually given to undergraduates in our colleges and technical schools. Outside of that, it makes extremely interesting reading for anyone who has no more than high school chemistry and half a desire to know how "everything new under the sun" is being made.

In bringing forth this revised edition the author is establishing the precedent of a revision every five years. Judging from the additional material made available during the past half-decade, there should be an even greater quantity of new subject matter by 1938. By that time there will be several full grown "Depression Babies" to write about. To this 1933 edition, four new chapters have been added, namely, on water and sewage, on synthetic organic chemicals, on phosphates including baking powders, and on synthetic resins. Other new items embrace: Neon signs, hydrogenation of mineral oils, air conditioning, American Potash mineral deposits, ammonia oxidation units instead of nitre pot, continuous retorts for wood distillation, the Suida process, thermal analysis of gases, pellet glue, nitriding of steel, and others.

The book starts off with a table showing the relative importance of Chemical and Allied Manufactures in the U. S. for the year 1929. Iron and steel head the list with 7½ billion dollars while ether and calcium arsenate share the tail-end honors with 1⅕ millions. In looking over the table of contents one's attention is caught by some of the more unusual titles: Products of the Electrothermal Furnace; Electrolytic Aluminum, Magnesium and Sodium; Processes Based on the Activity of Yeasts and Bacteria; Chemical Factors Other than Explosives in Warfare; Lithography; Patents; Appliances Used by the Chemical Engineer and, Instruments of Control Used by the Chemical Engineer.

T. K. CLEVELAND.

THERMODYNAMICS, by Alfred W. Porter, D.Sc., F.R.S., Emeritus Professor of Physics in the University of London, with a general preface by O. W. Richardson, F.R.S., Yarrow Research Professor of the Royal Society, Nobel Laureate in Physics, 1928. 93 pages, illustrations, 11 × 17.5 cms. New York, E. P. Dutton & Co., Inc. Price $1.10.

This pocket-size volume is a member of the series of Monographs on Physical Subjects. In accordance with its restricted size, the work becomes essentially an introduction to the subject of title—Thermodynamics. The author's aim has been to give an outline such as will enable a reader to understand the logical foundations of the subject. In addition, illustrations are given on how thermodynamic principles are applied in various parts of Physics with the intent that the reader may be able safely to apply them to additional problems of his own instigation.

Examples of detailed applications are omitted, such being left for inclusion in larger and more extensive works on the subject. The author introduces his topic by an introductory chapter which outlines the beginning of mechanics and the progressive change in conceptions concerning heat. The interrelation between heat and work is finally established and the law of thermodynamics given expression. Under the heading of reversible changes are discussed the Carnot cycle which graphs the law of efficiency; the development and practical use of the Entropy concept; equations of state and their significance; and, thermodynamics relations which particularly concern specific and latent heats. Under miscellaneous applications are to be found discussions on: Surface Forces, Thermoelectricity, Voltaic Cells and Dielectrics.

Irreversible Operations are of considerable importance and the author discusses more fully the Joule-Thomson effect and its applications to the determination of the thermodynamic scale of temperature. In this category the Wire Drawing of Steam and Refrigeration take their rightful places. No thermodynamic book would be complete without a discussion of equilibrium. This topic includes both the homogeneous and heterogeneous systems, the latter including a study of Phase Rule. Complications are introduced by surface tension and osmotic effects.

T. K. CLEVELAND.

LABORATORY PHYSICS, A STUDENT'S MANUAL FOR COLLEGES AND SCIENTIFIC SCHOOLS. By Dayton Clarence Miller, D.Sc., Professor of Physics in Case School of Applied Science, 438 pages, tables, illustrations, 14.5 × 21.5 cms. Boston, Ginn and Company. Price $3.00.

This interesting volume, which has been a college text for nearly thirty years, still meets all requirements of the higher schools. It is supplied with good illustrations and has many useful tables conveniently arranged.

It is to be regretted that in a work of this kind it is not possible to go into more detail. The several chapters contain only such data as are necessary for the student. Those who have a desire to know more can consult the author's several other works.

The writer is interested in water resonance apparatus, flutes, pitch pipes,

the psychrometer and color measurement—subjects which would have little appeal to the average student of physics. The book is not burdened with calculus, the various subjects are conveniently arranged and anyone who wants a satisfactory outline of modern physics can obtain it from Dr. Miller's book.

The author is to be congratulated and it is hoped that we may have the privilege of reading more from his pen.

HENRY EMERSON WETHERILL.

THE GREAT ENIGMA, A NEW VIEW ON THE OUTLOOK OF LIFE. By Hugo Hermann Schauinsland, Ph.D., President of the Municipal Museum of Natural History, Bremen, translated from the German by Walter H. Schauinsland, J.D., Ph.D., 93 pages, 13.5 × 19.5 cms. New York, E. P. Dutton & Co., Inc., 1933. Price $1.25.

Life is still the great enigma. To quote Professor Cheney of our own University of Pennsylvania in spite of the findings of science, inventions that have stimulated life to the panting point, man has as yet no answer to the two great interrogations—why does life adhere so scrupulously to the grooves and channels of type, and what was the start of life? Dr. Schauinsland is, according to his book, in much the same mood of interrogation.

His treatment of the enigma is philosophically stimulating to the contemplative mind, especially to one who can vibrate to Aristotle, Kant and Goethe. He describes psycho-physical parallelism and the reciprocal effect with much illustrating from biology. In the main he carries the attack against Darwinian selection with intriguing convincement. I don't know what the poor eels think of it in their cycle of life from the Sargasso Sea to the inland ponds and back again to the salt water. These same eels on their monstrous long journey have served Darwinian evolutionists and in this book they are called upon to demonstrate for the "entelechists."

Just a word about entelechy. It is designed to identify the activity of the psychic or the "psychoid" or, to quote page 50, "whatever we may call this power of Nature . . . nevertheless we do not know and never will discover what this psyche really is, whence it comes, whither it goes. It is part of the primary will which rules the whole cosmos, an image of the guiding logos, and is perhaps the soul of man on an exhalation of the exhalation of the all-pervading universal psyche?"

Words like "entrepy" of Eddington and the "entelechy" of Schauinsland may tie one up in a web, but it is good exercise to disengage oneself from the coils of the Great Enigma.

HOWARD W. ELKINTON.

CONSCIOUSNESS: BRAIN-CHILD, by Percy A. Campbell, 107 pages, 13.5 × 20 cms. East Cleveland, The Caxton Co., 1933.

Percy A. Campbell has written before and, by the trend of the text, he is likely to write again unless one concludes that the last word on consciousness has been written between the 107 pages of this book. I wish I could say it is readable. It is not. It is a very difficult book to read. His presentation is hard to understand and the language the man uses has to be gotten used to. For example:

"Nowthisconceptionofalogical Tower-of-Babel-likeflesh-and-bloodclosed systemofmutually-associatedmutually-resuscitatingcerebralfunctioningsenrapport withtheworldisagoodandsufficientgenericdescription I believeofanyandallformsof conscioushumanactivity."

Anyone who has had training in deciphering cursive Greek or disentangling Paul's epistles will find the above literary pie. Thank the Lord for the device of separating words and the pepper salt of punctuation sprinkled on top. Then, too, I feel thankful for good old sawed off, hard bitten Anglo-Saxon words. The phrase, for instance "remorse of conscience" is excellent in its place of torture, but how refreshing to hear one speak of the back-bite of in-wit. I entertain a wicked hope that Percy A. Campbell will suffer a little from the back-bite of in-wit for inventing so many hyphenated words but here I am crowned on two counts, both back-bite and in-wit.

Tower-of-Babel-like is not so bad. How about subject-ideoprocess? There is a lot about the subject-and-predicate-ideo-patterns-pulses-and-processes. In fact the whole treatise is on the consciousness-system or to put it another way "Consciousness is always a somewhat said about a something." That does not do the sentence justice. Read that chapter on Rapport and Liaison (page 20) and you will find the "what" and the "thing" in italics, which, of course, will make the meaning perfectly clear.

A few gems glisten when the light strikes at exactly the right angle.

> "A faithless Mother Nature would be incapable of evolving human children at all." (Page 33.)
>
> "Consciousness—including its putative quality—is always a synthetic thing, and each person carries the synthesis to a different point, or carries it along in a different manner." (Pages 47 and 48.) No doubt about a very great variation in syntheses.
>
> "Adaptive living is evolution's ultimate achievement." (Page 71.) A line that smacks of Darwin's teaching hardly fresh with Campbell.
>
> "Mind . . . is just a momentary but recurrent coruscation of cerebral life." (Page 101.)

But why continue the agony? Crack your head against a beam or bark your shin against the sharp spur of a chair rocker and then read the chapter on the consciousness of pain and you will be glad to add your bit to the race of murderers.

H. W. ELKINTON.

PUBLICATIONS RECEIVED.

Manufacture of Soda, with Special Reference to the Ammonia Process, a practical treatise, by Te-Pang Hou, American Chemical Society Monograph Series, 365 pages, illustrations, tables, 15.5 × 23.5 cms. New York, The Chemical Catalog Company, Inc., 1933. Price $8.00.

National Research Council, Bulletin No. 90, Physics of the Earth—VI, Seismology, by the Subsidiary Committee on Seismology, 223 pages, maps, illustrations, 17 × 25.5 cms. Washington, National Research Council, 1933. Price $2.50.

A Record of the Scientific Work of Sir James Dewar, 68 pages, 15.5 × 25 cms. London, Chiswick Press, 1933.

De la Turbine a l'Atome, par Rene Bied-Charreton, preface de M. Charles Fabry, 198 pages, 13.5 × 21.5 cms. Paris, Gauthier-Villars et Cie, 1933.

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United States Bureau of Mines, Mineral Resources of the United States, 1930, Part II—Nonmetals, 876 pages, tables, 15.5 × 23.5 cms. Washington, Government Printing Office, 1932. Price $1.50.

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Bell Telephone Laboratories, Monograph, B-742, Ash Constituents and the Electrical Conduction of Cotton, by A. C. Walker and M. H. Quell, 8 pages, 15 × 23 cms. B-743, Naturally-Occurring Ash Constituents of Cotton, by A. C. Walker and M. H. Quell, 14 pages, diagrams, 15 × 23 cms. B-747, An Experimental Apparatus for the Projection of Motion Pictures in Relief, by Herbert E. Ives, 9 pages, illustrations, 15 × 23 cms. New York, Bell Telephone Laboratories, 1933.

CURRENT TOPICS.

Infra-Red Photography.—(*Chem. and Ind.*, Vol. 52, p. 829.) In a paper dealing with Recent Developments, OLAF. F. BLOCH mentions a number of interesting and not generally known facts concerning the character and practical utilization of infra-red rays.

The renewed and widespread interest in infra-red photography has come mainly as a result of the improvements that have been made in infra-red sensitive photographic plates. The ordinary brom-iodo emulsion has a useful sensitivity range of about 3200 Å to about 5400 Å with a maximum sensitivity at 4600 Å. The range of visible light is 3900 Å and 7600 Å about, while the photographically sensible infra-red range at the present extends from the upper limit of the visible (about 7600 Å) to approximately 10,000 Å.

The history of infra-red investigations makes interesting reading and can be touched upon only very briefly at this time. Lehman developed an indirect method of infra-red spectrography which permitted him to go as far as 20,000 Å. The process depended upon the power of infra-red light to destroy phosphorescence. An excited phosphorescent screen will have its luminosity diminished or destroyed wherever infra-red radiation falls upon it. After a screen is thus exposed to the infra-red rays it is quickly placed in intimate contact with an ordinary photographic plate and the effect recorded. In 1881 Langley introduced the bolometer, an instrument that measured the heating effects of the rays. By means of the bolometer and wire gratings Rubens was able to measure down to 3,240,000 Å, that is, wave-lengths of nearly a third of a millimeter.

Considerable research has been expended in finding dyes which will render ordinary photographic emulsions sensitive to infra-red rays. One aim of the investigators is to find a dye that will have a maximum sensitivity at as great a wave-length as possible. Thus, Neocyanine isolated in 1926 has its maximum at 8300 Å while two new dyes, discovered just last year (1932) are Mesocyanine with a maximum at 8800 Å and Xenocyanine having a maximum at 9400 Å. The latter dye is very unstable and the plates containing it rapidly become veiled and useless unless they are kept in cold storage. The Ilford Laboratories, England have recently discovered a dye that permits the preparation of infra-red emulsions of considerably higher speed than has hitherto been possible.

Although no present-day theory on the process of optical sensitizing can be considered as thoroughly substantiated, there are

a certain number of valuable facts known. First, the dye adsorbed to the silver bromide is not firmly attached, since it can be washed out in the cold by employing suitable solvents. Secondly, the amount of dyestuff necessary to give optimal sensitizing is extremely small yet is sufficient to start a train of action similar both qualitatively and quantitatively to that produced by the light to which the silver halide was originally sensitive. In one instance the gram-molecular weight relationship between the dye and the silver bromide was in the ratio of 1 : 357,000. Thirdly, the effect does not necessarily depend upon the absorption of light of specific wavelengths since dyes possessing the same spectral absorption, vary enormously in their sensitizing power, some having none at all. The mere substitution of a dimethyl for a diethyl grouping will decrease sensitizing power. Fourthly, there is no evidence of any preferential absorption onto the sensitive nuclei of the silver halide grains.

Sources of infra-red light are not at all scarce; in fact, every hot body or object radiates such invisible infra-red rays. If a lamp filament or piece of metal is brought to a temperature of 400° C. no visible light of any kind can be observed, but radiation in the neighborhood of 9000 Å is present. At 420° C. the iron could just be perceived as a grey body by the dark-adapted eye. A convenient source of infra-red radiation is the ordinary gas-filled electric lamp. Of course it is necessary to use a light filter over the camera lens, to absorb all the visible light and transmit infra-red light only. A certain number of dyes when in solution transmit infra-red light freely, as does also a solution of iodine in carbon disulphide, certain glasses containing oxides of iron and managnese and these can serve as light filters. Since most infra-red plates possess very feeble green sensitivity, a fairly bright yellow-green safelight containing a substance which absorbs the infra-red may be employed.

Although scarcely advanced beyond the experimental stage, infra-red photography would appear to have a number of very important uses. A picture of an electric flat iron held at a temperature of 400° C. was recorded by means of its infra-red radiation upon an exposure of 14 hours. The negative was found to give an excellent reproduction of the heat gradient in the iron and the heat distribution could readily be demonstrated by measuring the photographic densities of the exposed plate.

Infra-red rays, unlike those of light, are not appreciably absorbed by fogs, mists or haze hence photographs may be made with infra-red plates under conditions that render the use of ordinary light-sensitive ones practically impossible. Aerial photographers have recently utilized the infra-red to take pictures of mountains 310 and

331 miles distant. Even the earth's curvature may be demonstrated with the aid of such photographs. Photoelectric cell records show that the infra-red content of daylight undergoes a rapid increase not long after sunrise, regardless of whether the sky is clear or cloudy.

The fact that chlorophyll both reflects and transmits, but does not absorb, that portion of the infra-red light to which the plates used are sensitive, is responsible for foilage generally appearing disproportionately dark on the negatives and giving the impression of a snowstorm on the positive. Flowers and fruit exhibit the same phenomenon. The absorption spectrum of an alcohol extract of chlorophyll shows complete transmission from 6800 Å onwards.

Dyestuffs greatly affect the behavior of fabrics toward infra-red light. Insufficient work precludes the drawing of any definite conclusions but it appears as though the sulfur colors, on the whole, reflect but little infra-red. What is more, no general relationship appears to exist between the infra-red reflection and visual color. Woods vary greatly in their abilities to transmit, but in thicknesses of $\frac{1}{8}$ in. the majority of those examined proved to be transparent. American walnut and ebony were opaque. Untreated paper is quite transparent but may be rendered opaque by coloring with carbon black, a pigment which absorbs infra-red light strongly.

Recently, infra-red photography has been applied with success in the examination of certain historical documents. About 300 years ago the Inquistition Censor saw fit to blacken out whole pages in a copy of "Theodore de Bry's Voyages." Upon photographing, the obliterating ink was found to be sufficiently transparent to infra-red rays so as to render visible the type beneath it. In the British Museum are some fragments of leather covered with hieratic script almost entirely illegible, and date from about 1200 B.C. a period when hieratic writing was passing into the hieroglyphic. Infra-red photographs of this fragment rendered the writing sufficiently clear to be decipherable.

The making of infra-red photographic portraits has produced some startling results. In some cases they reveal hair beneath the skin of clean-shaven males, probably owing to pigmentation differences; in other cases, the entire features of the sitter appear to be modified, never to advantage. In one instance of a photograph of a negro, changed racial characteristics were observed, and it is therefore possible that the process might find occasional use in ethnological studies.

Considerable use has been made of the infra-red method in astronomy. The planet Mars photographed by infra-red light is smaller than the image recorded with visible light. An infra-red photograph of the Orion nebula showed images of many faint stars

invisible in the usual photograph. A recently made infra-red spectrograph of Venus showed the carbon dioxide bands of the planet's atmosphere. These bands do not appear in the solar spectrum.

Infra-red radiation also proves valuable in microscopy, particularly where the specimens are not satisfactorily transparent to ordinary light. This greater penetrating power of the infra-red rays has indicated its advantage to medicine in the study of infections and diseases of the skin. In cases of eczema the rays penetrate below the skin and clearly outline the venous circulation and the varicose veins which usually accompany this condition. In cases of lupas treated with ultra-violet radiation the whole of the skin is generally covered with scab. An infra-red photograph ignores the scab to a considerable extent and reveals the healed areas underneath.

C.

Free On Noise.—For some time now Dr. E. E. FREE has busied himself with noises, sometimes seeking them, more often taking them as they come. Dr. Free's activities were not for the purpose of developing a course on noise appreciation; his interest is more detached: he classifies noises according to their intensities.

Between the faintest audible sound and the loudest noise there lies an intensity range which the human ear is capable of dividing into more than 100 increments. These detectable units of change in sound intensity are termed "decibels." Naturally the faintest sound detectable by the ear is accorded an intensity of 0 decibels. Defined in absolute terms, the "decibel zero" is equivalent to a sound energy of 1×10^{-16} watts per square centimeter. Under ordinary conditions this value represents 0.207 millibar sound pressure. The decibel scale is arranged according to the common logarithm of the power or energy ratio. To put it more simply, 10 decibels represent an amplification of 10 times; 20 decibels, 100 times; 30 decibels, 1000 times and so on.

Now that a scale to represent sound intensities had been chosen, the next step was to build an instrument which would make possible a rapid and accurate determination of these intensities. Such a piece of apparatus has been developed under Dr. Free's supervision. The latest type of Noise Meter is a rugged, cheap, easily portable and highly flexible instrument for the accurate measurement of noise or other sound, entirely independent of the human ear. The instrument is self-contained, is independent of outside electric supply and can be used by anyone as easily as a voltmeter or a thermometer. The apparatus consists of a magnetic micro-

phone, a three-stage amplifier, an electric meter and the necessary dry batteries. The microphone converts the sound waves to be measured into an electric signal, which then is amplified in a known ratio and measured on the electric meter, reading directly in decibels.

These meters have many applications. They may be used for measuring noise in offices or other rooms before and after noise-reducing treatment, for the use of salesmen selling noise-reducing materials, for the use of health departments or other legal officers in inspecting alleged noise nuisances, for city noise surveys, for factory or field inspection of fans, motors, refrigerators and other mechanical equipment, for the study of airplane noise and for the majority of other problems of practical noise engineering. Teachers of music and of elocution have utilized the noise meters so both student and teacher may observe and control the loudness variation of the voice or of musical instruments.

The present popular type of Noise Meter is calibrated for an intensity range extending from 35 decibels to 125 decibels. A noise of 35 decibels is about that of a quiet residence in the country. One of 120 decibels is about that of an unmuffled airplane engine 15 feet from the ear. Only noise differences of less than 20 decibels may be read directly on the decibel meter. For greater differences the scale is adjusted to the desired range by means of an attenuator reading directly in 5-decibel steps.

When measuring ordinary types of noise and other reasonably continuous sounds consisting of numerous frequencies mixed together, the regular type of Noise Meter indicates the energy of the sound accurately over the frequency range between 200 cycles and 3500 cycles per second. Within the above stated ranges of intensities and frequencies the energy measurements are found to agree with the relative loudness as determined by the average human ear. For intensities and frequencies beyond these ranges and where single-frequency sounds such as musical tones are concerned, certain modifications of the Meter are necessary.

The Noise Meter is equipped with two input jacks providing for the convenient attachment of a separate microphone, a vibration pick-up or any other input device. An output jack permits the attachment of any type of indicating or recording meter, of a reverberation meter, of an oscillograph, of a loudspeaker or headphones, or of any other acoustic or electric device. By using the input and output jacks, the Noise Meter may be operated as a self-contained amplifier, having a constant power gain of 80 decibels and a frequency characteristic flat to one decibel between 100 and 8000 cycles per second.

Several interesting accessories can be supplied with the Noise

Meter. A separate microphone can be provided for use inside sound-proof rooms or boxes. Electrical pick-up devices for the measurement of mechanical vibration in solids can readily be attached to the meter. A separate decibel meter may be connected up and provide visual demonstration to a large audience by means of an epidiascope. The output jack permits the attachment of any desired type of recording meter for the purpose of keeping a continuous record. There is a frequency analyzer which separates mixed sounds into eight frequency bands, corresponding to musical octaves. A Hum Filter can be had which eliminates the 120-cycle hum sometimes emitted by electrical machinery and to which the average ear is relatively insensitive. There is also available a Reverberation Meter designed to measure the reverberation time of rooms. The output jack also permits the attachment of automatic warning signals or governors to operate various types of controls or alarms when the noise intensity exceeds a predetermined value.

Now that there is such a thing as a Noise Meter let us see what it can tell us regarding the intensities of the many noises familiar to all. To date, the loudest noise is made by an airplane engine and propeller and it is not at all surprising to find the boiler factory a close second. The former exhibits a range of 110–125 decibels while the latter reaches 105–115 decibels. According to Dr. Free the greatest noise of all probably occurred way back in 1883. In the strait of Sunda, between the islands of Java and Sumatra, stood the volcano of Krakatoa. When this blew up the detonation was heard nearly 3000 miles away and the shock traveled seven times around the earth. The estimated intensity of that explosion is placed at about 190 decibels.

Just below the boiler factory in noise intensity comes the pneumatic riveter, while thunder is fourth. A roaring lion and Niagara Falls share equally the fifth place honors with 95 decibels apiece. An average city street may range from 50 to 80 decibels; a dog barking, 70; while the average conversation varies between 65 and 75 decibels. Turning the page of a paper rattles off 30 decibels while a purring cat can do 25 with ease. Strange as it may seem, an underground vault in New York City registers 22 decibels because of reverberations. And the lowest ordinary sound of all may be heard by a person if he will go alone into a sound-proof room and listen to his heart beat at an intensity of 10 to 15 decibels. Stiller than that is death.

C.

Rennin.—In the stomach, the digestion of proteins is due to the action of pepsin, the coagulation of the casein of milk to the action of rennin. According to some authorities, pepsin and rennin are two distinct enzymes. According to other authorities, the two reactions (proteolysis and coagulation) are produced catalytically by two different side chains of the same molecule. Pepsin in the crystalline state has been known for several years. ISRAEL S. KLEINER (*Hahnemannian Monthly*, 1933, LXVIII, 610–613) endeavored to crystallize rennin obtained from the fourth stomach of the calf. While he failed to obtain crystals, his final, concentrated product had an activity of 1 : 4,500,000, i.e., one part of the rennin produced coagulation of 4,500,000 parts by weight of skimmed milk. This rennin possessed practically no power to digest egg albumin in acid solution, therefore differed from pepsin. The two enzyme preparations (crystalline pepsin and concentrated rennin) differed in other respects, e.g., in behavior on dialysis, reactions for precipitation, and response to color tests. Pepsin and rennin are separate and distinct enzymes. Rennin apparently is a thioproteose, pepsin a simple protein.

J. S. H.

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